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Module 4

Energy for Motion

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Physics 20

Module 4

Energy for Motion

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Physics 20
Student Module
Module 4
Energy for Motion
Alberta Distance Learning Centre
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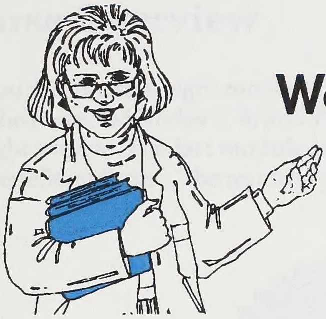

Welcome to Module 4!

We hope you'll enjoy your study of *Energy for Motion.*

To make your learning a bit easier, watch the referenced videocassettes whenever you see this icon.

You also have the option of viewing laser videodisc clips when you see the bar codes like this one.

Frame 48350A

When you see this icon, study the appropriate pages in your textbook.

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PRINCIPLES AND PROBLEMS

Good Luck!

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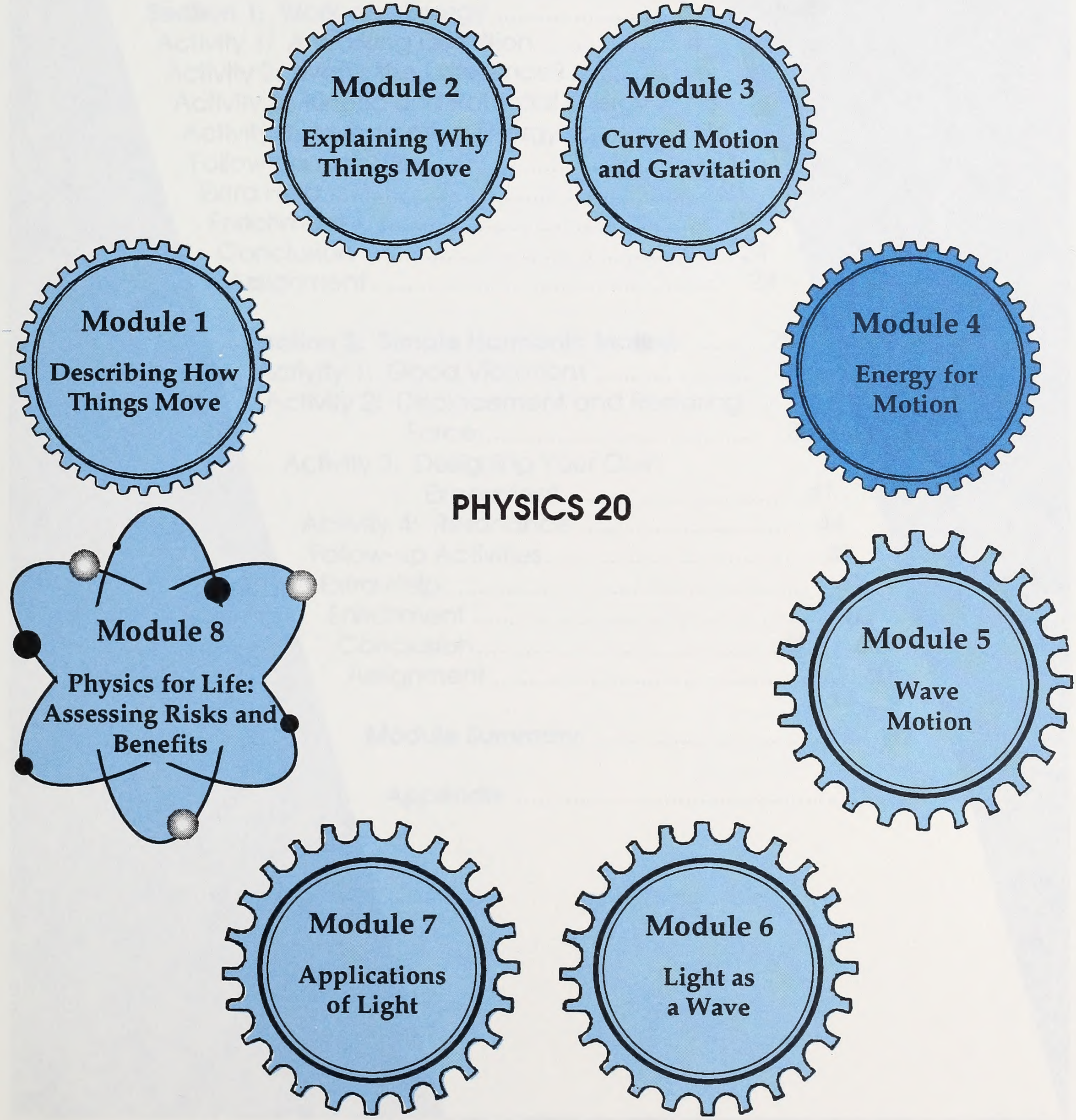
Course Overview

This course contains eight modules. The first four modules involve the study of motion on Earth and in the heavens. Modules 5, 6, and 7 investigate the properties and characteristics of waves in general and light waves. The last module is an introduction to nuclear physics from the point of view of risk/benefit analysis. The module you are working in is highlighted in darker colour.



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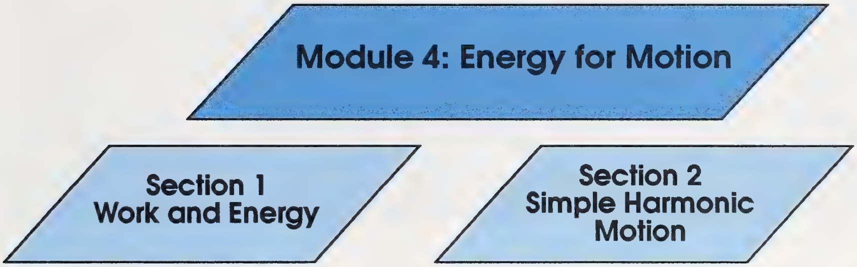
OVERVIEW

The previous modules introduced you to the concepts of kinematics and dynamics – how and why objects move. The following modules introduce you to the concepts of waves and wave motion, the properties of light, and radioactivity. You may ask yourself what the connection is between moving cars, satellites orbiting around Earth, waves crashing on a tropical beach, light coming from a fluorescent lamp, and the operation of a CANDU reactor. The answer is simple – energy!

In this module you will review the concepts of work and energy that you learned in Science 10 and then you will begin to study a special type of vibration called simple harmonic motion.



Evaluation

Your mark in this module will be determined by your work in the Assignment Booklet. You must complete all assignments. In this module you are expected to complete three section assignments. The mark distribution is as follows:

Section 1 Assignment	37 marks
Section 2 Assignment	63 marks
TOTAL	**100 marks**

Section

1

Work and Energy

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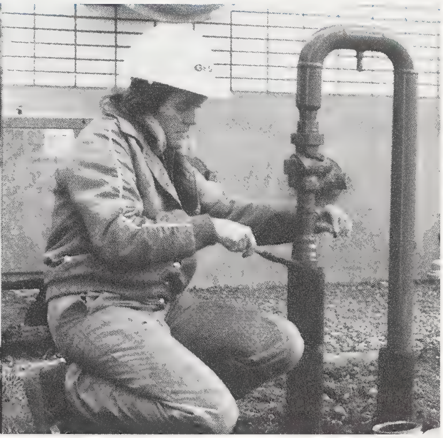
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Have you ever noticed that the word *work* is used to describe every type of job? Who does more work, an accountant or a construction worker? In each case, the person involved may be exhausted at the end of the day! How would you decide who does the most work?

In this section you will discover that a very specific definition of the term *work* is used in physics. You will use that definition as a means of classifying and accounting for the changes in energy within any system. At the end of this section you will have a chance to investigate the energy changes which occur in a simple system.

Activity 1: A Working Definition

Many of the words that you use in everyday conversation are also used in physics. You may experience some confusion about the difference between the way that a physicist uses a word and the way that you use the same word. This activity will illustrate the different usages of the word *work*.

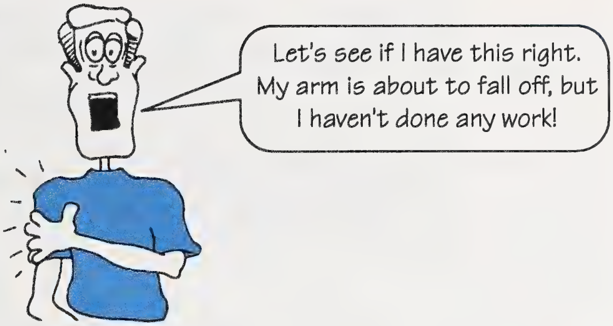
Hold your physics textbook in either your left or right hand. Lift your arm straight out from your side so that the book is level with your shoulder.

How long can you hold your arm in this position? Are you holding your arm straight out? Don't let it fall below shoulder level! Most people find that even a minute of this is enough to produce cramping muscles!

1. Would you say that holding your arm in this position requires work? Explain why you answered the way you did.

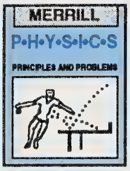
2. Would you do more or less work if you were to hold the book in this position for two minutes instead of one minute?

How many minutes were you able to keep your arm level with your shoulder? Half a minute? One minute? Two minutes? According to the laws of physics, you have not done any work, regardless of how long you held up the book!


Let's see if I have this right. My arm is about to fall off, but I haven't done any work!

work – the mathematical product of force and displacement

Don't be confused! You have done work, but you have not done any work on the book! The confusion lies in the definition of **work.**

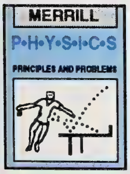


Read pages 196 to 198 of your textbook to familiarize yourself with the way that work is defined by physics.

So, work is done on an object only if you apply a force which causes the motion of that object.

Your desk or table has no difficulty holding your books and papers in one place. Why?

Work is not done unless some motion occurs. When you were holding up your textbook, you were doing work, but the work was not done on the book. It was done moving various ions across cell membranes within the muscles of your arm to maintain muscle contraction.

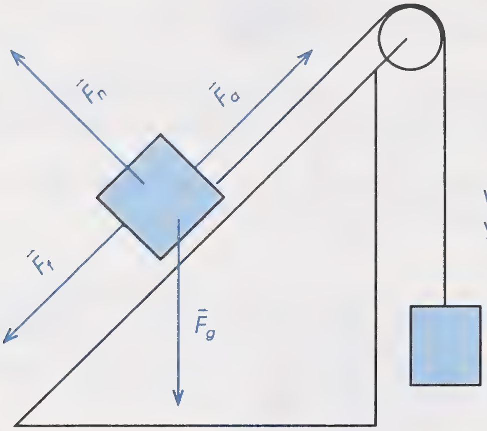


3. Answer Applying Concepts question 1 on page 212 of your textbook.

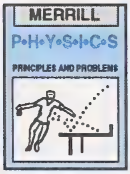
Check your answers by turning to the Appendix, Section 1: Activity 1.

Activity 2: Watt's the Difference?

So, who does more work, an accountant or a construction worker? To answer this question, it is necessary to observe the activities each person does and apply the definition of work. However, most movement is the result of more than one force. To simplify matters, you will evaluate the application of a single force on an object.



Which force would you use to calculate work?



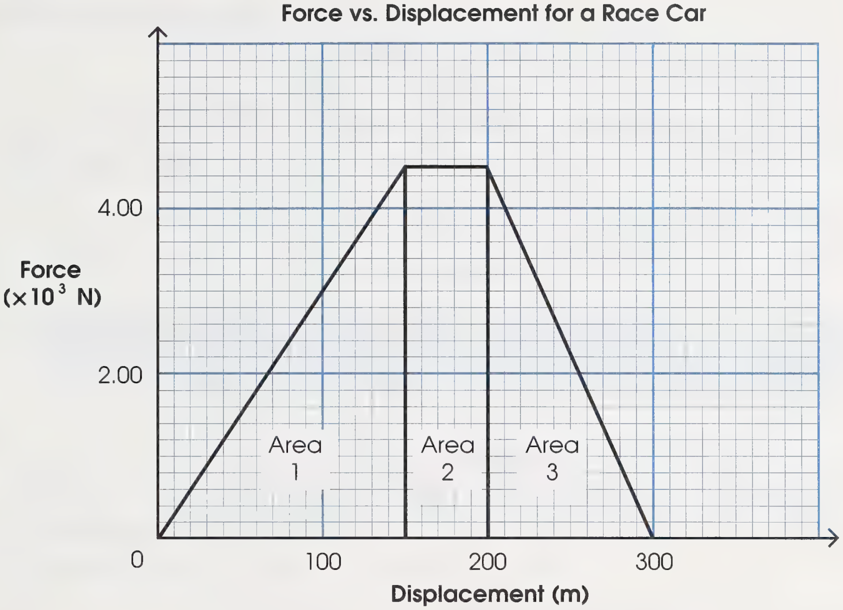
To calculate the amount of work done on an object, you can use one of two methods – the graphical method or the algebraic method. For examples of each type of calculation, read page 199 of your textbook.

To lift an object at a constant velocity, you must apply an average force that is equal to the weight of the object because slightly more force is needed to start the object moving and less force is used as the object stops.

Does this type of calculation seem familiar? It should. You worked with both of these methods in Science 10! However, since these types of calculations may get quite involved, a few more examples are shown.

Example 1

A race car may give the following simplified graphical relation between applied force and displacement.



$$\begin{aligned}W &= \text{the area under the curve of a force-displacement graph}\\ &= \text{Area } 1 + \text{Area } 2 + \text{Area } 3\\ &= \tfrac{1}{2}(\text{altitude})(\text{base}) + (\text{altitude})(\text{base}) + \tfrac{1}{2}(\text{altitude})(\text{base})\\ &= \tfrac{1}{2}\left(4.50\times10^{3}\ \text{N}\right)(150\ \text{m}) + \left(4.50\times10^{3}\ \text{N}\right)(50\ \text{m}) + \tfrac{1}{2}\left(4.50\times10^{3}\ \text{N}\right)(100\ \text{m})\\ &= 7.88\times10^{5}\ \text{N}\bullet\text{m}\\ &= 7.9\times10^{5}\ \text{J}\end{aligned}$$

When graphically calculating work, it is important that you only evaluate the areas which apply to the question.

Example 2

If you were to calculate the work done only in the last 150 m of Example 1, you would perform the following calculation.

$$
\begin{aligned}
W &= \text{the area under the curve of a force-displacement graph}\\
&= \text{Area } 2 + \text{Area } 3\\
&= (\text{altitude})(\text{base}) + \frac{1}{2}(\text{altitude})(\text{base})\\
&= \left(4.50 \times 10^{3}\ \text{N}\right)(50\ \text{m}) + \frac{1}{2}\left(4.50 \times 10^{3}\ \text{N}\right)(100\ \text{m})\\
&= 4.50 \times 10^{5}\ \text{N} \bullet \text{m}\\
&= 4.5 \times 10^{5}\ \text{J}
\end{aligned}
$$

Your answer will change significantly, depending on the exact portion of the graph used.

Example 3

A 2.00×10^{3}-kg truck starts from rest and accelerates to a final speed of 100 km/h (27.8 m/s) in 35.0 s. What is the work done in accelerating the truck?

$$W = Fd$$

To solve for work, displacement and force must be calculated first!

$v_i = 0.00\ \text{m/s}$
$v_f = 27.8\ \text{m/s}$
$t = 35.0\ \text{s}$
$d = ?$

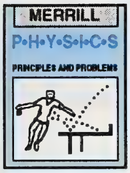
$$
\begin{aligned}
d &= \left(\frac{v_f + v_i}{2}\right)t\\
&= \left(\frac{27.8\ \text{m/s} + 0\ \text{m/s}}{2}\right)35.0\ \text{s}\\
&= 486.5\ \text{m}
\end{aligned}
$$

$v_i = 0.00\ \text{m/s}$
$v_f = 27.8\ \text{m/s}$
$t = 35.0\ \text{s}$
$a = ?$

$$
\begin{aligned}
a &= \frac{v_f - v_i}{t}\\
&= \frac{27.8\ \text{m/s} - 0\ \text{m/s}}{35.0\ \text{s}}\\
&= 0.7943\ \text{m/s}^{2}
\end{aligned}
$$

$$\begin{aligned} W &= Fd \\ &= mad \\ &= \left(2.00\times10^{3}\ \text{kg}\right)\left(0.7943\ \text{m/s}^{2}\right)\left(486.5\ \text{m}\right) \\ &= 7.73\times10^{5}\ \text{N}\bullet\text{m} \\ &= 7.73\times10^{5}\ \text{J} \end{aligned}$$

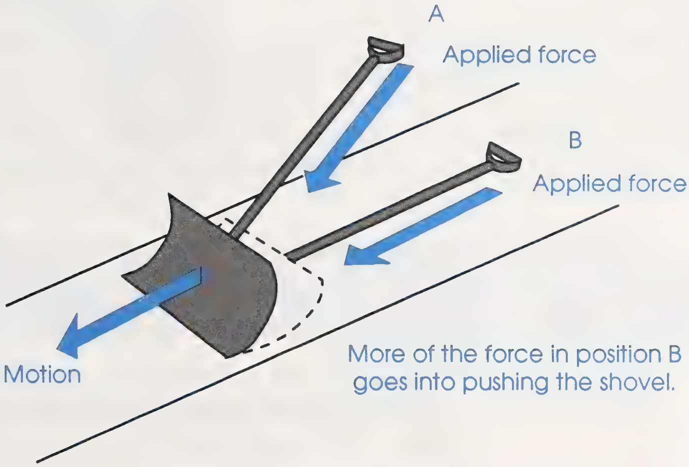
The following questions will allow you to practise the techniques shown in the previous examples.



1. Answer Problems 1, 2, 4, and 5 on page 213 of your textbook. You may want to do question 4 last because it is more challenging than the others.

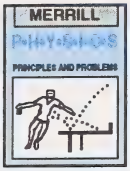
Check your answers by turning to the Appendix, Section 1: Activity 2.

Not all of the force applied to an object causes motion. For example, when you shovel snow, it is easier to push if you drop the handle of the shovel to a lower position.



More of the force in position B goes into pushing the shovel.

For this type of situation you must modify your approach.



Carefully read pages 200 and 201 of your textbook to discover how to modify your approach to determine the work done on an object by the application of a force. Pay special attention to the example given on page 201.

Lowering the handle of the shovel reduces the force into its perpendicular components. When calculating, use the component of force which acts in the direction of the motion.

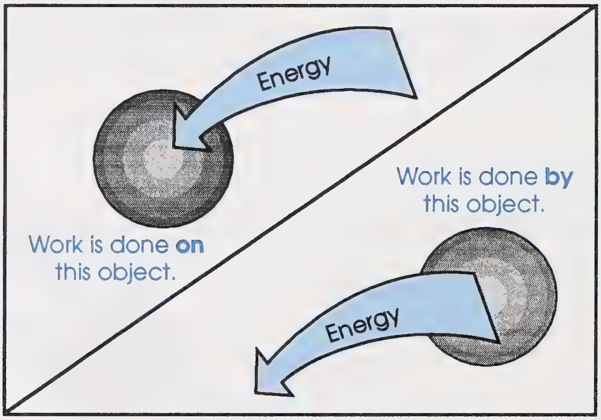
The following questions will allow you to practise this type of problem.

2. Do Practice Problems 6 and 7 on page 202 of your textbook.

Check your answers by turning to page 671 in your textbook.

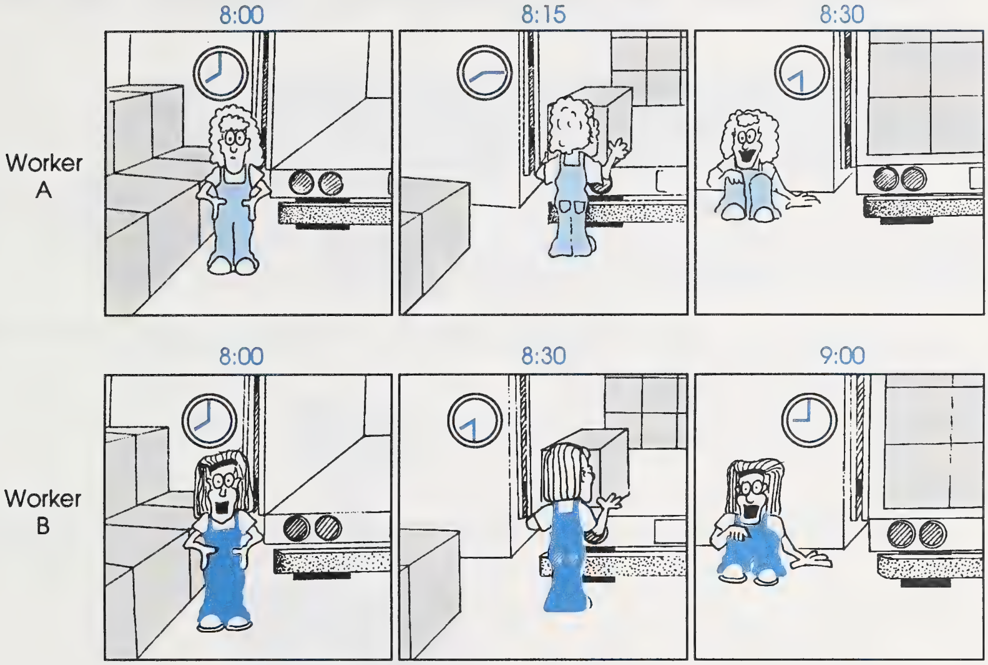
The problems you have just finished may have helped clarify the Science 10 definitions of work and energy. **Energy** is no longer defined in terms of work, and work is no longer defined in terms of energy.

energy – the capacity of an object to create a disturbance within that object or its immediate surroundings


Energy
Work is done **on** this object.
Work is done **by** this object.
Energy

In order for work to be done **to** an object, energy must be applied to the system. For work to be done **by** an object, energy must be released by the system.

3. Which worker does more work, Worker A or Worker B?



Many people have difficulties with this concept! Worker A did finish in half the time, but did she work harder? Does time have anything to do with how much work is done? The same amount of energy is being expended by both workers, so the same amount of work is being done. However, the energy is being expended at different rates, so there is some difference. Worker A has demonstrated more **power**.

power – the rate at which energy is moved between two objects or systems

Check your answers by turning to the Appendix, Section 1: Activity 2.

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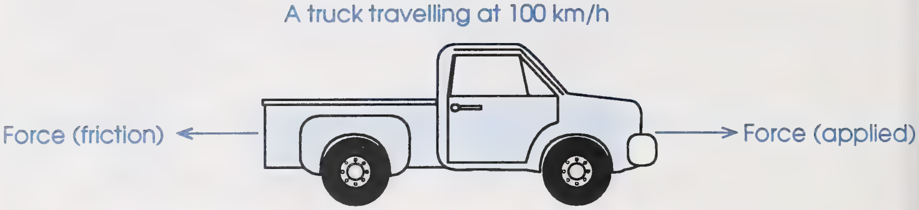
PRINCIPLES AND PROBLEMS

Carefully read the section called Power on page 202 of your textbook. Study the example shown on pages 202 and 203.

4. Practice Problems 9 and 10 appear on page 203 of your textbook. If you had no problem understanding the concept of power and the example presented in your textbook, do question 10. If you had difficulty with the concepts, do question 9.

Check your answers by turning to page 671 of your textbook.

In many cases, especially those involving friction, an applied force may not result in an acceleration, but will only cause an object to remain in a state of uniform motion.



For this type of situation, the equation for power can be modified as follows:

$$\boxed{P = \frac{W}{t}}$$

$$\Big\downarrow$$

$W = Fd$, so substitute these variables into the equation.

$$\boxed{P = \frac{Fd}{t} = F\left(\frac{d}{t}\right)}$$

$$\Big\downarrow$$

Remember that $v = \frac{d}{t}$. Substitute v into the equation.

$$\boxed{P = Fv}$$

Example

How much power does it take to lift a 100-kg steel beam at a constant 1.50 m/s?

- The force required to lift the 100-kg mass is equal to its weight.

$$F = mg = (100\text{ kg})(9.80\text{ m/s}^2) = 980\text{ N}$$

- The power is found using the equation that was just derived.

$$P = Fv = (980\text{ N})(1.50\text{ m/s}) = 1.47 \times 10^3\text{ W}$$

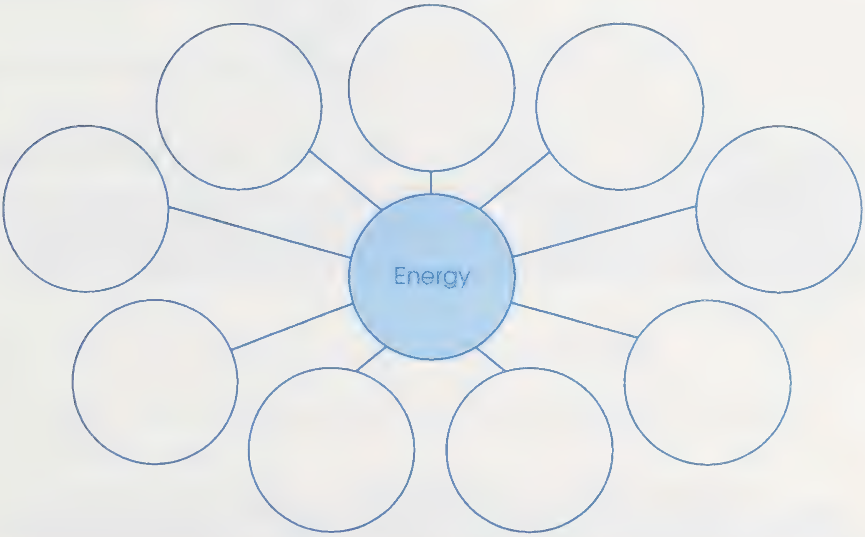
5. Ernst must push his stalled car to a safe location. Pushing the car requires a force of 325 N, which gives the car a speed of 1.8 m/s. Calculate the power required from Ernst.

Check your answers by turning to the Appendix, Section 1: Activity 2.

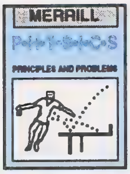
Activity 3: Kinetic and Potential Energy

In Activity 2 you learned that when a force is exerted to accelerate an object, energy is transferred to that object. In Science 10 you learned that energy causes change. The photograph on the cover of this module booklet illustrates that there are many different forms of energy involved in the launch of a space shuttle.

1. How many different types of energy can you think of? Try to fill in all the circles.



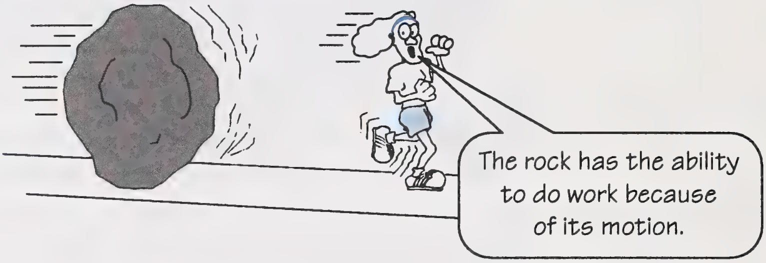
Check your answers by turning to the Appendix, Section 1: Activity 3.



In Science 10 you were introduced to the concept of **kinetic** and **potential** energy and the mechanics of energy conversion. To refresh your memory of the concept of kinetic energy and the work-energy theorem, carefully read pages 216 to 220 in your textbook.

kinetic energy – the energy possessed by an object which is in motion

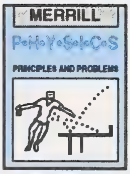
potential energy – the energy stored in an object due to its location or shape


The rock has the ability to do work because of its motion.

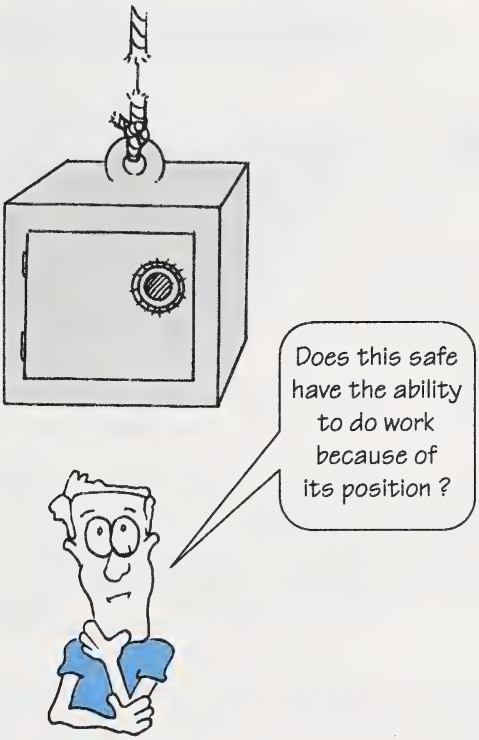
2. Study the Example Problem on page 221 of your textbook. Then do Practice Problem 2 on page 222 of your textbook.

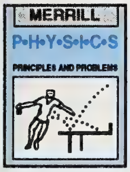
Check your answers by turning to page 672 in your textbook.

You may have noticed that these calculations are not very different from the ones which you did in Science 10.



For a quick review of gravitational potential energy, read pages 222 to 224 in your textbook.


Does this safe have the ability to do work because of its position ?



3. Do Practice Problems 5, 6, 7, and 8 on page 224 of your textbook.

Check your answers by turning to page 673 in your textbook.

4. Turn to page 238 of your textbook and do question 14.

5. What does the negative sign in your answer to textbook question 14 signify?

Check your answers by turning to the Appendix, Section 1: Activity 3.

Activity 4: Investigating Energy

Science Skills

☐ A. Initiating
☑ B. Collecting
☑ C. Organizing
☑ D. Analysing
☐ E. Synthesizing
☐ F. Evaluating

PATHWAYS

If you have access to laboratory facilities, do Part A.
If you do not have access to laboratory facilities, do Part B.

Part A involves doing a laboratory investigation about the transfer of energy which occurs for a pendulum.

Part B provides students with sample laboratory data for the experiment described in Part A. You are to use this data to complete the investigation. Since the sample data was collected using a procedure similar to Part A, you should read Part A to understand how the data was obtained before beginning Part B.

Part A

Materials

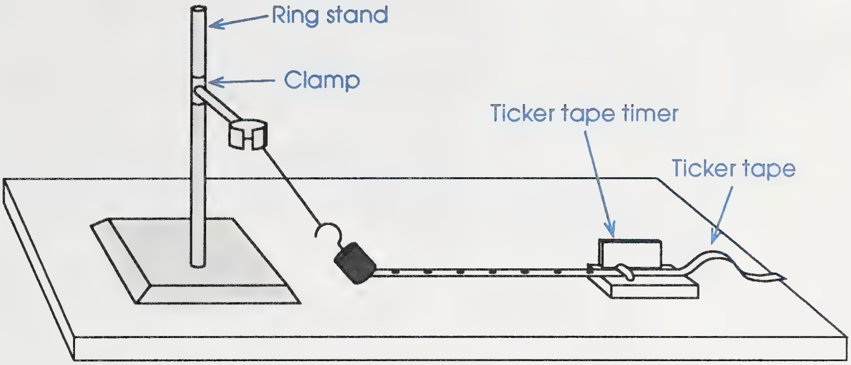
The following materials are needed to complete this investigation:

- 500-g mass
- ticker tape
- ticker tape timer
- string
- metre stick
- ring stand
- ring clamp or test tube clamp
- masking tape

Procedure

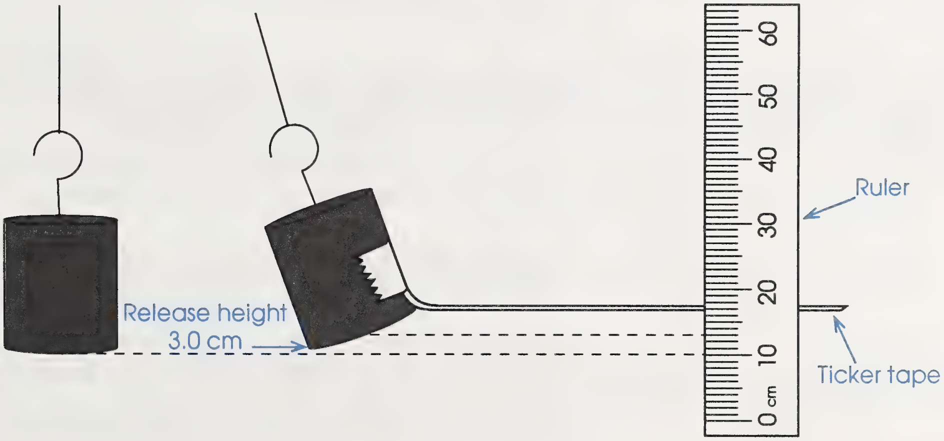
1. • Calculate the period of your ticker tape timer by counting the number of dots produced on a tape pulled at a constant speed through the timer for 5.0 s.

- Set up the apparatus as shown in the diagram.



- Attach the end of the tape to the 500-g mass with masking tape. Using the bench or desktop as your reference point, measure the height of the 500-g mass when it is hanging straight down. For best results, you should use a pendulum that is at least 0.5 m long. You may measure to any part of the pendulum as long as the same part of the pendulum is used for each measurement.

- Move the pendulum to one side until the vertical height of the pendulum is 3.0 cm (0.030 m) above its original position. This is the release height.



- Start the timer and release the pendulum. Stop the timer when the pendulum begins its return swing. Examine the ticker tape. Label the release height on the ticker tape (release height = 3.0 cm).

- Repeat the procedure for another two trials using release heights of 5.0 cm and 10.0 cm. Be sure to label each tape.

- Begin the Analysis and Interpretation section which follows Part B.

End of Part A

Part B

Materials

You will need the following materials for this investigation:

- scissors
- tape

Procedure

- Read through the procedure given for Part A to understand how the data was collected.

- Carefully cut out the ticker tape from the Appendix. Arrange the ticker tape in alphabetical order and tape it together.

2. Calculate the period of the ticker tape time by counting the number of dots that were produced in the 2.0-s time interval.

- Carefully cut out and put together the ticker tapes for each of the trials. These tapes are also found in the Appendix.

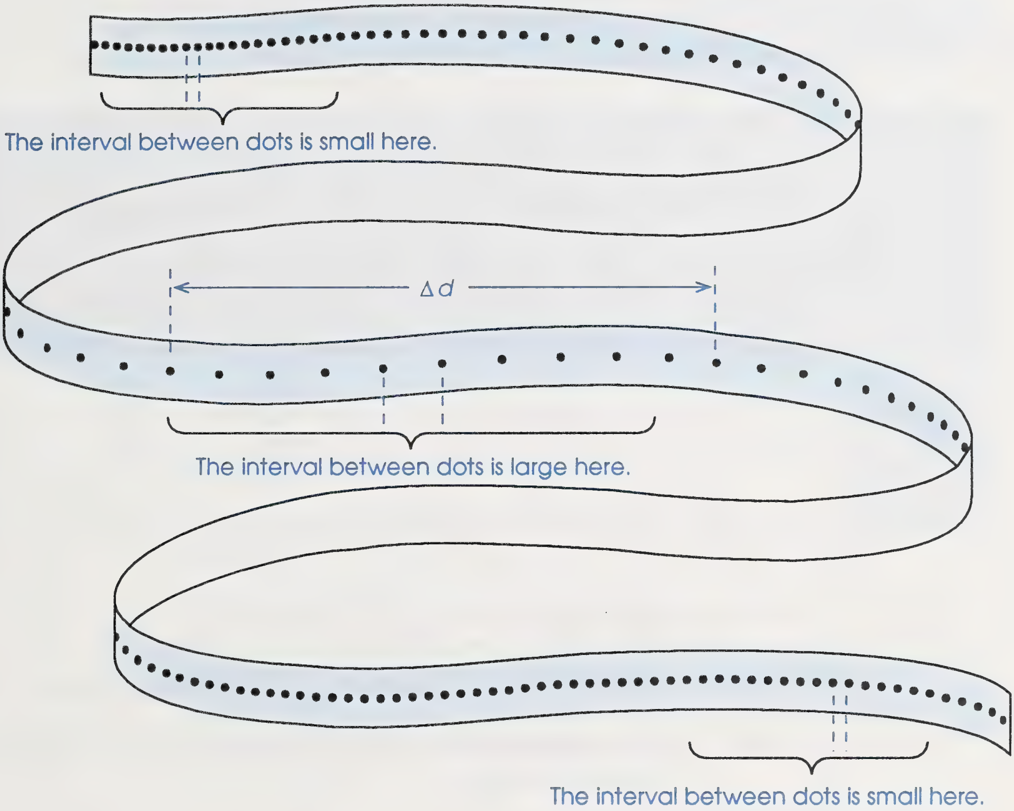
- Cut out the ruler that is provided so that your answers are consistent with the sample answers provided in the Appendix.

- Do the Analysis and Interpretation questions which follow.

End of Part B

Analysis and Interpretation

3. Calculate the maximum speed of the pendulum by measuring the distance and time associated with the ten largest consecutive dot intervals on the ticker tape for each of the three trials. The ten largest consecutive dot intervals will likely occur around the middle of the ticker tape.


The interval between dots is small here.
Δd
The interval between dots is large here.
The interval between dots is small here.

4. Use the calculated value for maximum speed to calculate the maximum kinetic energy for each trial. Record the values on the data chart.

5. Calculate the maximum potential energy by using the value for the release height. Do this for each trial and record the values on the data chart.

6. Calculate the percent difference between the maximum potential energy and the maximum kinetic energy for each trial. Record the values on the data chart.

$$\text{percent difference} = \frac{(\text{maximum } E_k) - (\text{maximum } E_p)}{\text{maximum } E_p} \times 100\%$$

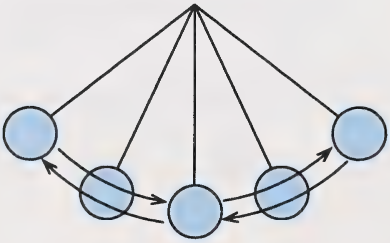
Data

Data for Pendulum Investigation							
	Data for Maximum E_k				Data for Maximum E_p		
Trial	Distance (m)	Time (s)	Maximum Speed (m/s)	Maximum Kinetic Energy (J)	Release Height (m)	Maximum Potential Energy (J)	Percent Difference (%)
1							
2							
3							

Conclusions

7. Why was it recommended that the pendulum be at least 50 cm long?

8. Label the points at which the pendulum has its maximum kinetic and potential energies.



9. Based on your results, would you agree that the change in potential energy equals the change in kinetic energy? Explain your answer.

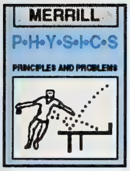
10. What was the greatest source of experimental error in this investigation? Suggest how you could reduce this error.

Check your answers by turning to the Appendix, Section 1: Activity 4.

Follow-up Activities

If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help



1. Turn to page 237 of your textbook and answer Applying Concepts questions 1 and 4.
2. Turn to page 236 of your textbook and answer Reviewing Concepts question 7.
3. Turn to page 239 of your textbook and answer Problem 22. A good strategy for this problem would be to determine how much work it takes to pull back the string and then apply the work-energy theorem.
4. Complete the chart on the next page to help summarize the main ideas from this section.

Summary Chart for Work and Energy

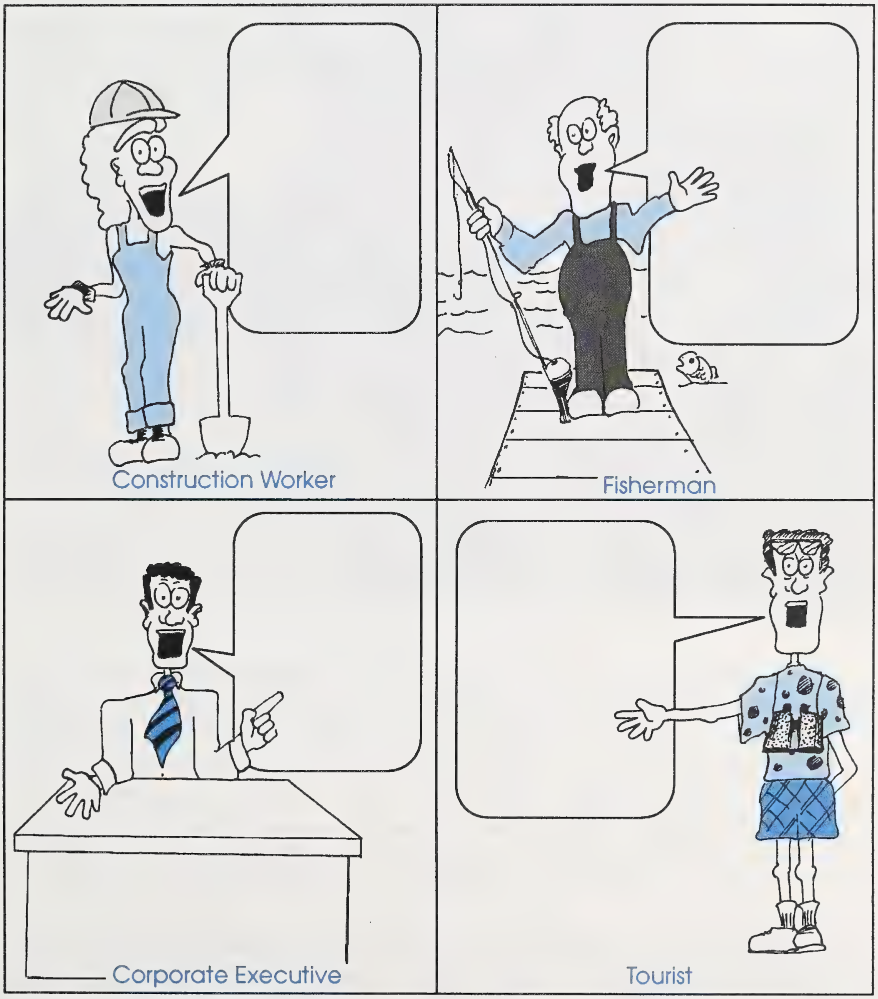
Term	Meaning	Symbol	SI Units	Equation(s)
Work				
Energy				
Kinetic Energy				
Potential Energy				
Power				

Check your answers by turning to the Appendix, Section 1: Extra Help.

Enrichment

Do **one** of the following activities.

1. Carefully read the Physics and Society section on page 232 of your textbook. Think about the advantages and disadvantages of the proposed dam. Put yourself in the position of each of the people shown in the following chart. Would each person support the construction of the dam? Fill in an answer for each person in the appropriate speech balloon. Try to give a good reason for each answer.



2. The unit for work and energy is the joule. Research the life and work of James Prescott Joule.

3. If you have access to the booklet called Critical Thinking which comes with the teacher resource package for your textbook, turn to page 16 of the booklet and do the activity called Endless Energy!

Conclusion

This section of Module 4 has focused on the concepts of work, power, and energy. You have had the opportunity to review and revise the concepts that were originally presented in Science 10. You will continue to use these concepts as you proceed to Section 2 for a discussion of simple harmonic motion.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 1.

Section

2 Simple Harmonic Motion

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Swimming with friends in a lake or river is one of the best ways to enjoy a hot summer day. It's even better if the swimming hole has a rope that lets you swing out over the water before taking that big plunge. If you were swinging on this kind of rope, what factors would determine how long it would take you to move from the starting point to the point where you let go of the rope? Would a heavier person take more time to move through this distance? Does the length of the rope matter? These questions can be answered through the study of simple harmonic motion.

In this section you will explore the properties of objects exhibiting simple harmonic motion. You will use the conservation of mechanical energy to predict and explain the properties of simple harmonic motion. You should gain an appreciation for the ways that simple harmonic motion influences your daily life.

simple harmonic motion – the motion exhibited by any vibrating system in which the force which restores the system to its equilibrium position is a linear function of the system's displacement

Activity 1: Good Vibrations

You are probably already familiar with the main ideas of simple harmonic motion. If you have any difficulties while studying this concept, you'll find that it is often helpful to think back to those early experiences with a playground swing since it is an ideal demonstration of simple harmonic motion.

The following questions will introduce you to the main ideas of simple harmonic motion.

PATHWAYS

If you have access to the video entitled *Harmonic Motion*, do Part A. If you do not have access to the video, do Part B.

Part A

Watch the video *Harmonic Motion*. As you watch the video, you may wish to stop it occasionally to complete the questions which appear in this part of the activity.

You will be referring back to this video in Module 5, so pay close attention, especially to the section on resonance.

1. Match the definitions in Column A with the appropriate term from Column B.

Column A

_____ the maximum amount of displacement in a vibratory (oscillatory) motion

_____ the number of oscillations or vibrations completed in some fixed time

_____ the time required to complete one vibration or oscillation

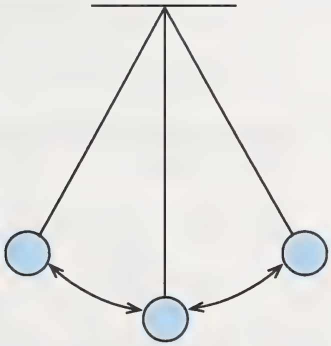
_____ The application of the displacing force on a system matches the natural frequency of that system.

_____ A disturbance creates a restoring force and the restoring force causes the system to overshoot the equilibrium point, which causes a restoring force...

Column B

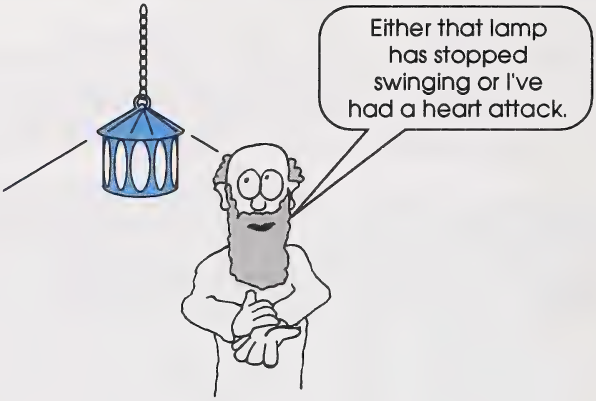
a. stable system
b. period
c. resonance
d. frequency
e. amplitude

2. The following diagram illustrates a simple pendulum. Label the equilibrium point and amplitude.



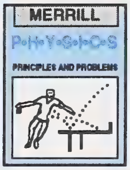
3. Galileo is credited with many discoveries in physics. In the video *Harmonic Motion,* he is said to have made a very important discovery regarding harmonic motion. Describe Galileo's discovery.

4. Why was Galileo's discovery so valuable?


Either that lamp has stopped swinging or I've had a heart attack.

End of Part A

Part B



Carefully read page 147 of your textbook to learn what simple harmonic motion means. Then answer the following questions.

5. Define *simple harmonic motion.*

6. How would you measure the period for the mass on the spring?

7. Draw a diagram to show the amplitude for the mass on the spring.

Continue your introduction to simple harmonic motion by carefully reading pages 148 and 150.

8. How would you measure the period of a pendulum?

9. Draw a diagram to illustrate the amplitude of a pendulum.

10. Give an example of how you might use the idea of resonance.

End of Part B

Check your answers by turning to the Appendix, Section 2: Activity 1.

period – the length of time for an object to complete one vibration or oscillation

You probably noticed that the **period** of an object exhibiting simple harmonic motion is used to describe the motion of the object. In the next investigation you will learn what factors influence the period of a pendulum.

Investigation: Determining the Period of a Pendulum

Science Skills

- ☐ A. Initiating
- ☑ B. Collecting
- ☐ C. Organizing
- ☐ D. Analysing
- ☐ E. Synthesizing
- ☑ F. Evaluating

Purpose

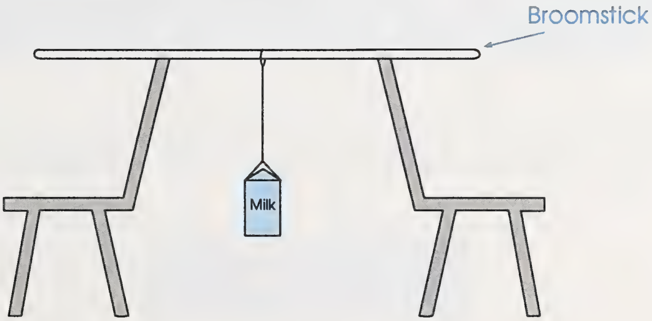
The purpose of this investigation is to compare the period and amplitude of a simple pendulum.

Materials

- two chairs
- broomstick
- 50 cm of string
- 500-g mass or a 1-L milk carton half-filled with water
- stopwatch
- protractor

Procedure

- Suspend the 500-g mass or the milk carton from the broomstick as shown in the diagram.



- Draw the pendulum bob back until the string makes a 5° angle with the original vertical position.

11. Release the pendulum bob and measure the time taken by the bob to complete ten oscillations (one oscillation is one complete swing back and forth). Record the time on the data chart.

12. Repeat the procedure for another three trials using angles of 10°, 30°, and 60°.

Data

Release Angle (°)	Time for Ten Swings (s)	Period (s)
5°		
10°		
30°		
60°		

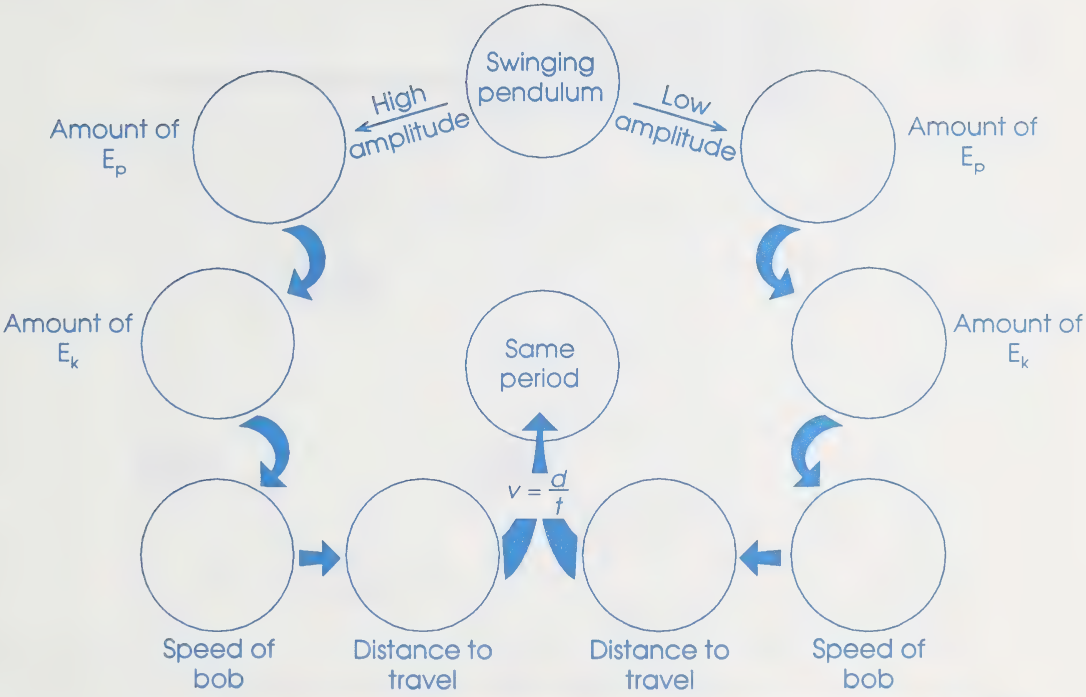
Analysis

13. Complete the data table.

14. Compare the periods obtained for each of the different release angles. What do you notice?

Conclusion

15. Complete the following diagram by writing **high** or **low** in the circles.



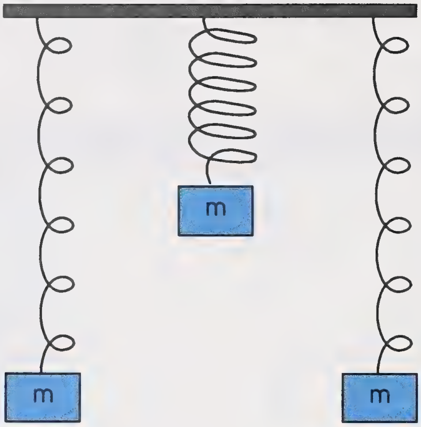
Check your answers by turning to the Appendix, Section 2: Activity 1.

The period of an object is useful for describing the vibrations of the object. In general, the period of an object is given by the following equation.

$$\boxed{T = \frac{\text{number of seconds}}{\text{one vibration}}}$$

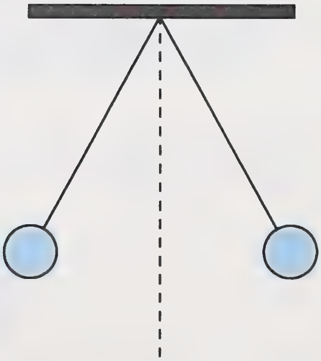
Consider this example.

A mass vibrates up and down on a spring. The mass is observed to move from the bottom to the top and then back to the bottom of its path 60 times in 15 s. What is the period of vibration for the mass?



$$T = \frac{15 \text{ s}}{60 \text{ vibrations}} = 0.25 \text{ s}$$

16. A pendulum takes 0.75 s to move from its position on the far right to its position on the far left. Determine the period of this pendulum.



frequency – the number of vibrations or cycles per second

Another useful term for describing an object that undergoes simple harmonic motion is **frequency**. The frequency tells you how often the motion is occurring.

Frequency

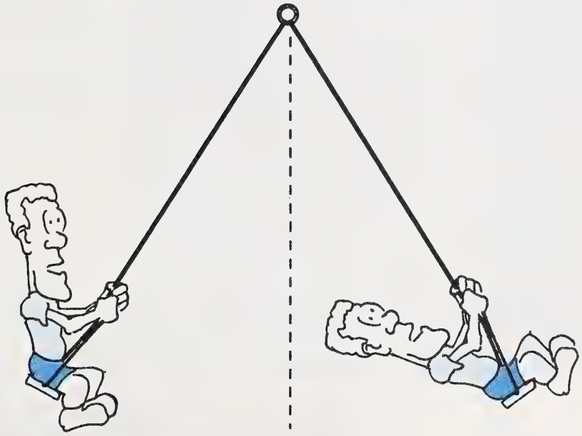
$$\boxed{f = \frac{\text{number of vibrations}}{1\ \text{s}}}$$

Also called the number of cycles

The following example illustrates how to use this equation.

A person swings forward and then back 200 times in 3 min. Determine the frequency.

$$\begin{aligned} f &= \frac{200\ \text{cycles}}{3\ \text{min}} \\ &= \frac{200\ \text{cycles}}{180\ \text{s}} \\ &= 1.\overline{1}\ \text{cycles/s} \\ &= 1.\overline{1}\ \text{Hz} \end{aligned}$$



Notice that the unit for frequency can be written as cycles per second or as hertz.

$$\boxed{1\ \text{Hz} = 1\ \text{cycle/s}}$$

17. A guitar string can make 3930 vibrations in 15 s. What is the frequency of vibration for the guitar string?

18. The highest pitched sound that a human can hear causes the eardrum to vibrate back and forth 1 200 000 times in 1.0 min. What is the frequency of this sound?

19. There is an interesting relationship between period and frequency. Complete the calculations in the following chart to discover this relationship.

Calculating Period and Frequency

Object Vibrating	Number of Vibrations	Total Time for Vibrations	Calculation of Period (s)	Calculation of Frequency (Hz)
Person on Swing	60	150 s		
Pendulum of a Grandfather Clock	1800	60 min		
Your Eardrum with the Lowest Pitched Sound that You Can Hear	200	10 s		
Your Eardrum with the Highest Pitched Sound You Can Hear	20 000	1 s		
An Electron in the Back of Your Eye Absorbing Blue Light	6.7×10^{14}	1 s		

20. Based on your calculations from the last question, what is the relationship between period and frequency?

While answering the last two questions, you may have noticed the wide range of topics that the physics of periodic motion can be applied to. In the next module you will extend the physics of vibrations to water waves and sound waves. In Modules 6 and 7 you will use periodic motion to study ligh waves, and, if you take Physics 30, you will extend your investigation of vibrations to include electric current and electromagnetic waves.

Activity 2: Displacement and Restoring Force

How can you recognize simple harmonic motion? If you are observing an object that is vibrating, what do you need to know to be able to say that the vibration is a simple harmonic one?

Examine the diagrams and margin notes on page 147 of your textbook to determine the key characteristics of simple harmonic motion.

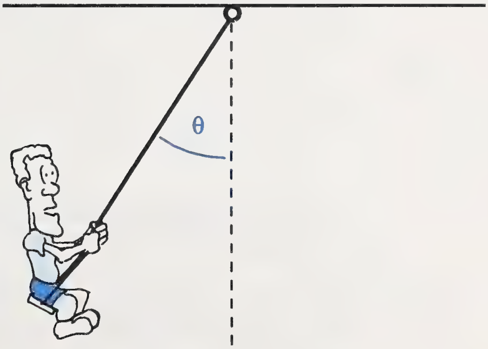
1. What characterizes simple harmonic motion?

restoring force – the force supplied to an oscillating mass which causes it to return to its equilibrium position

Do you remember playing on the swings when you were little? You learned to pump your legs so that you could keep swinging. Although you always tried to get higher and higher, you kept swinging back. There is a force called the **restoring force** which always returns the pendulum bob, or the swing, back to the equilibrium point. It is a feature of all simple harmonic oscillators that the restoring force must be directly proportional to the displacement of the oscillating mass from its equilibrium point, and that the restoring force acts in the opposite direction to the displacement.

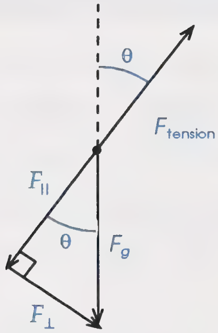
For more information on the restoring force, look at the diagram of the pendulum at the bottom of page 148 in your textbook.

2. On the following diagram, complete the vector diagram by drawing in the force due to gravity and the tension.



3. Now do the free body diagram with the swinger replaced by a dot. Recall from Module 2 that a free body diagram is a force diagram that is free of the body.

To find the restoring force, you need to find the perpendicular components of the weight of the swinging mass.



One component is parallel to the force of tension and the other is perpendicular to the force of tension. You can find the equations for each of these by using trigonometry.

The parallel force is found by using the following equation.

$$\cos\theta = \frac{F_{\parallel}}{F_g}$$

$$F_{\parallel} = F_g\left(\cos\theta\right)$$

4. Determine the relationship between the perpendicular component and the gravitational force.

The parallel force is opposite in direction to the displacement of the swinging mass, so it is the restoring force. As long as the angle of a pendulum is less than 15°, the pendulum is an example of simple harmonic motion.

Check your answers by turning to the Appendix, Section 2: Activity 2.

Investigation: The Restoring Force for a Pendulum

Purpose

In this investigation you will try to find a relationship between the size of the restoring force and the displacement from the vertical.

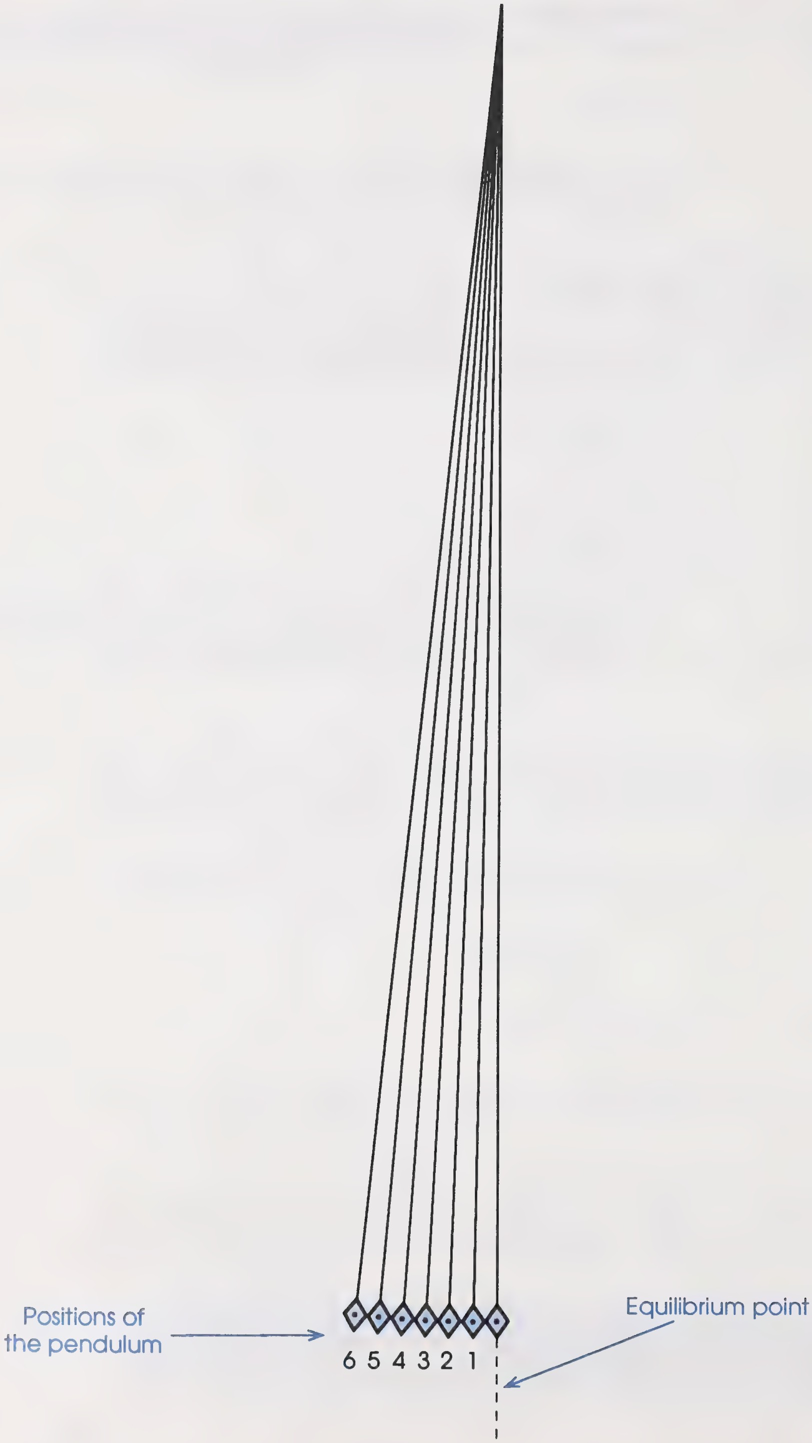
Materials

You will need these materials for this investigation:

- protractor
- ruler

Procedure

- Carefully examine the diagram of the exact positions in the swing of a pendulum on the following page. The diagram shows the pendulum swinging to the left from the equilibrium point.


Positions of the pendulum
Equilibrium point
6 5 4 3 2 1

5. Measure the angle from the equilibrium point to each of the positions shown. Record your measurements on the data chart.

6. Carefully measure the displacement from the equilibrium point to each position of the pendulum. Be sure to measure to the centre of each pendulum. Record these values on the data chart.

Data

Data from the Scale Diagram of a Pendulum

Position of the Pendulum	Angle (°)	Displacement (mm)	Restoring Force (N)	Acceleration (m/s^2)
Equilibrium Point	0.0	0		
1	1.0	3.5		
2				
3				
4				
5				
6				

Calculations

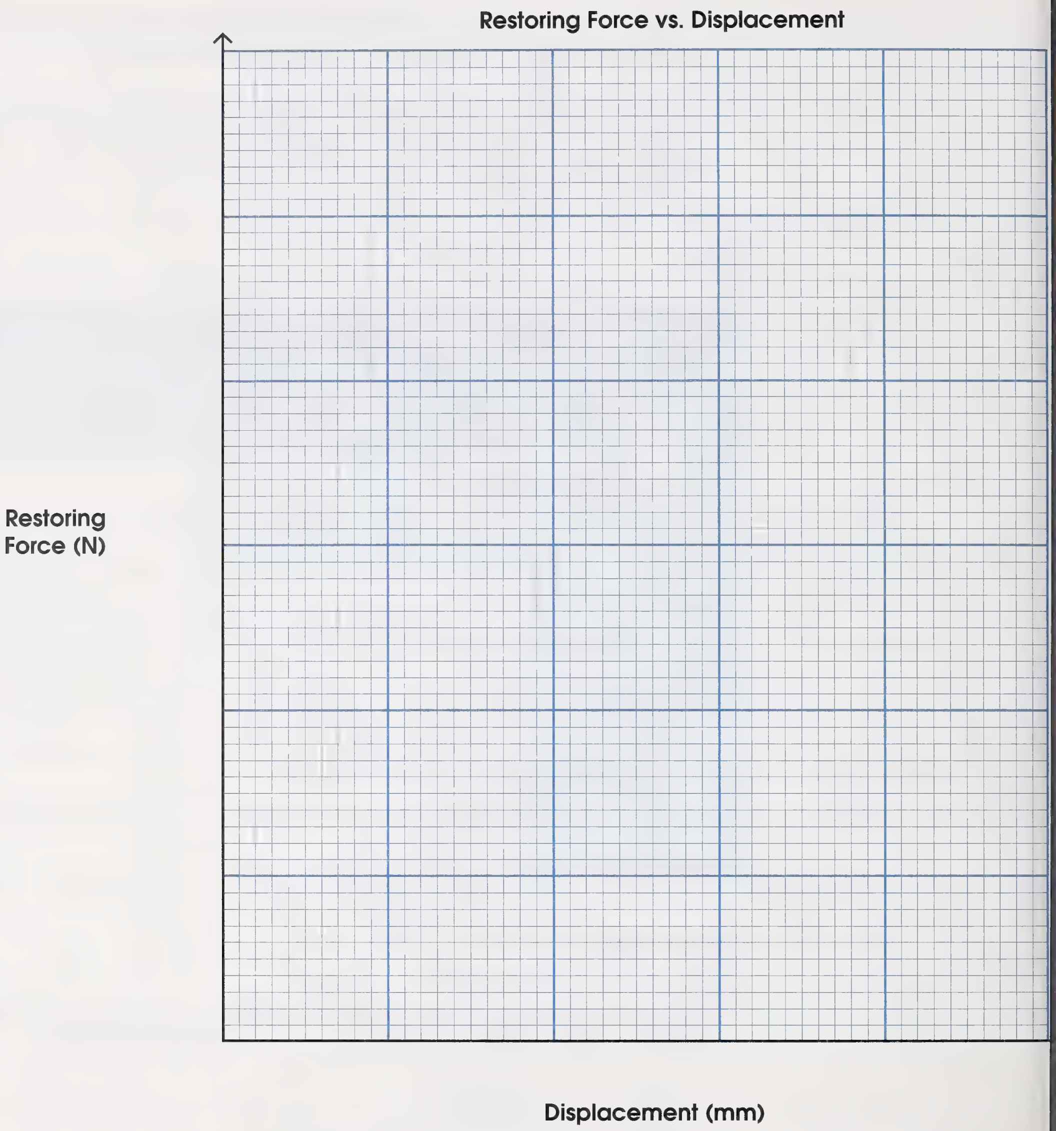
7. Use the following equation to calculate the restoring force for each position. Remember that the mass of the pendulum is 1.00 g.

$$F_{restoring} = F_g\left(\sin\theta\right)$$

8. Use Newton's second law to calculate the acceleration for each position.

Analysis

9. Plot the restoring force versus the pendulum's displacement on the next page.



10. Draw the best fit line. How would you describe this line?

Conclusions

11. How does the restoring force vary with displacement?

12. How do you think acceleration varies with the displacement? Explain your reasoning.

13. Based on your answers to the last four questions, is the motion of the pendulum a simple harmonic motion?

Check your answers by turning to the Appendix, Section 2: Activity 2.

Activity 3: Designing Your Own Experiment

In the Activity 2 you were introduced to the concepts and details involved with simple harmonic motion. This laboratory investigation involves the use of a pendulum to explore and confirm the properties of simple harmonic motion introduced in Activities 1 and 2.

Investigation: Verification of the Equation for the Period of a Pendulum

Background Information

A pendulum is a good example of a simple harmonic oscillator as long as the angles involved are small (less than 15°). You may have used the fact that a pendulum exhibits simple harmonic motion back when you measured the acceleration due to gravity in Module 1. In Module 1 the following equation was introduced to describe the period of a pendulum.

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Science Skills

- ☑ **A. Initiating**
- ☑ **B. Collecting**
- ☑ **C. Organizing**
- ☑ **D. Analysing**
- ☑ **E. Synthesizing**
- ☑ **F. Evaluating**

Purpose

In this investigation you will design a procedure which compares the actual period and the expected period of pendulums with five different lengths. You will then use those results to validate the derived relationship between period and length.

1. Write a complete list of all the materials that you will need. Include a diagram to illustrate the experimental setup.

2. Write the detailed step-by-step procedure that you will follow as you complete the investigation.

3. Record the data on an organized data table.

4. Complete an error analysis of the data and then suggest major sources of error and methods to reduce these errors.

5. Based on your answer to question 4, state whether you think you verified the equation.

Graphical Analysis to Determine a Value for *g*

An interesting result of this sort of investigation is that it is possible to graphically use the data from a pendulum to measure the acceleration due to gravity.

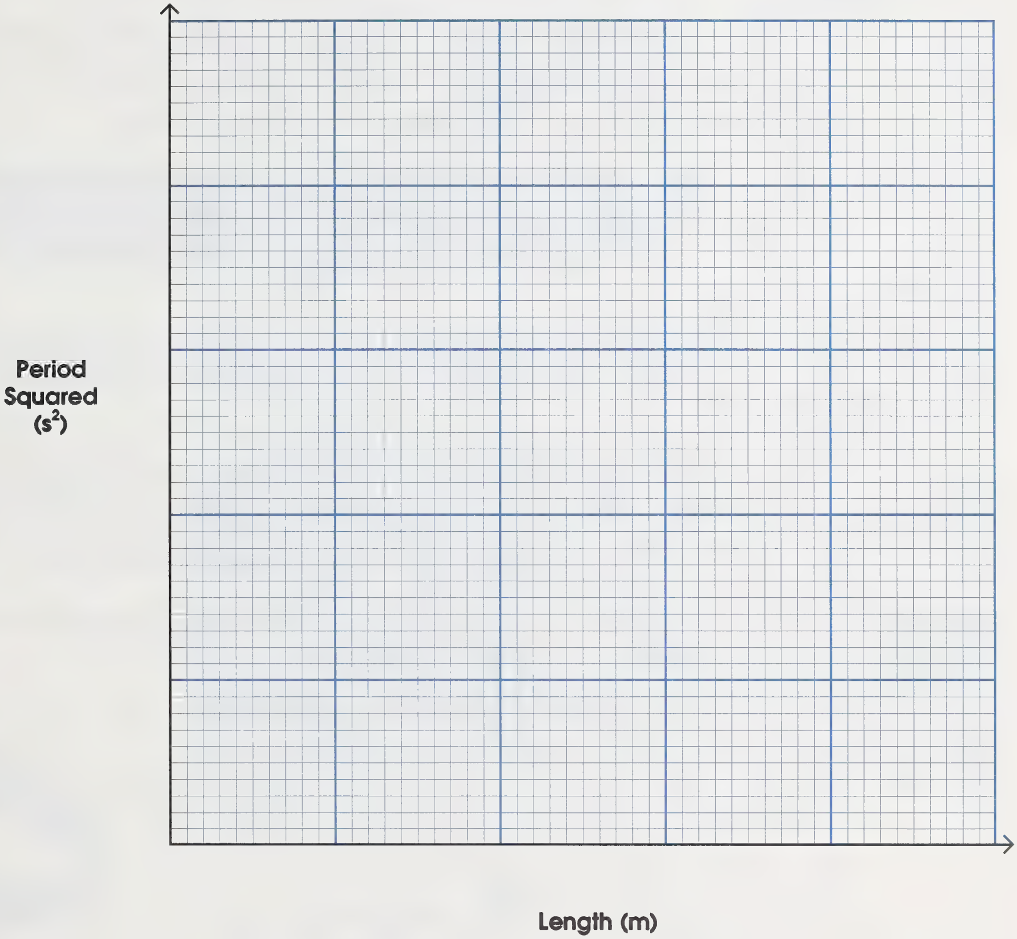
6. Complete the following data table from your measurements of length and period.

Length and Period Squared Data

Length of Pendulum (m)	Period of Pendulum (s)	Period Squared (s^2)

7. a. Prepare a graph of the period squared versus the length of the pendulum.

Period Squared vs. Length



b. Draw the best fit straight line.

8. Find the slope of the graph.

9. What does the slope of the graph represent in terms of the physics of this investigation?

10. Combine your answers to questions 8 and 9 to find an experimental value for the acceleration due to gravity.

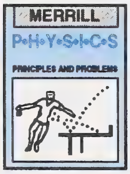
11. Calculate the percent error for this investigation.

In this activity you confirmed the relationship between the length and period of a pendulum undergoing simple harmonic motion, as discovered by Sir Isaac Newton. In the next activity you will take a look at the conservation of energy and the way it applies to oscillating systems.

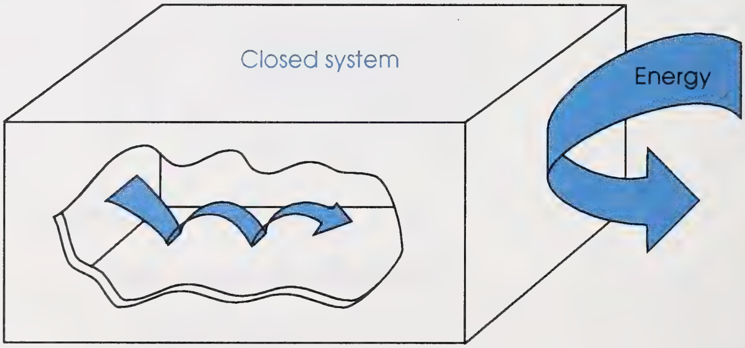
Check your answers by turning to the Appendix, Section 2: Activity 3.

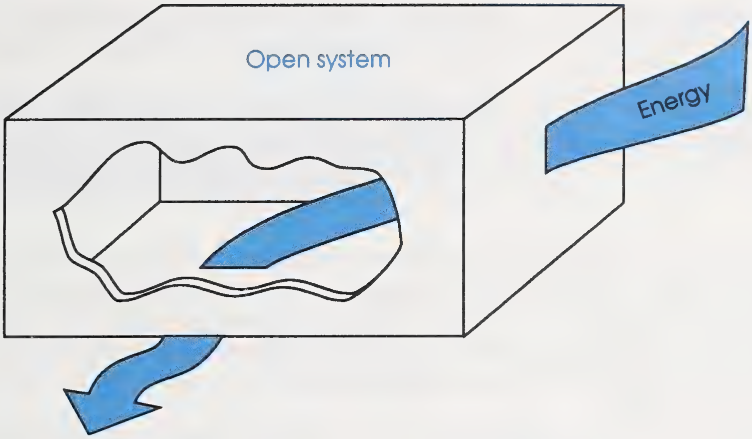
Activity 4: Resonance

In Activities 1 and 2 you were given the chance to observe the motions of objects undergoing simple harmonic motion. You've been asked to think about being on a swing and pumping your legs to keep the swing going. What were you really doing when you were pumping your legs? In this activity you are going to study the energy principles of vibratory motion.



Read pages 227 to 229 in your textbook. Pay particular attention to Figure 11-11 on page 228 and Figure 11-12 on page 229.



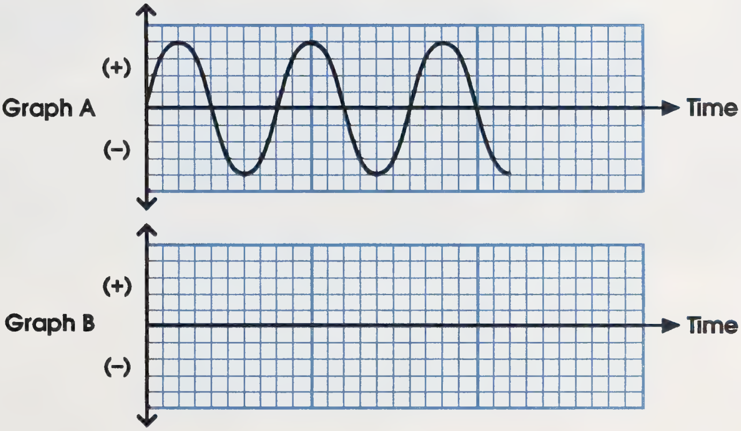


closed system – The objects which comprise the system are isolated from outside forces.

Up until now you have been dealing with closed systems, but, as pointed out in the textbook, a closed system is a special case. All real-life situations will deal with systems in which energy can be lost or transferred out of the system.

Think back to your experiences on a swing. After you had been swinging for awhile, you may have wanted to stop. You might have just ridden the swing until it stopped, or else you might have dragged your feet on the ground to slow it down. Because your displacement was decreasing, you were losing energy, most likely due to the friction of the swing or your feet against the ground.

1. Graph A gives the displacement-time graph for an idealized swing (harmonic oscillator). On graph B sketch the amplitude-time graph which would occur for a person riding on the swing without pumping their legs.



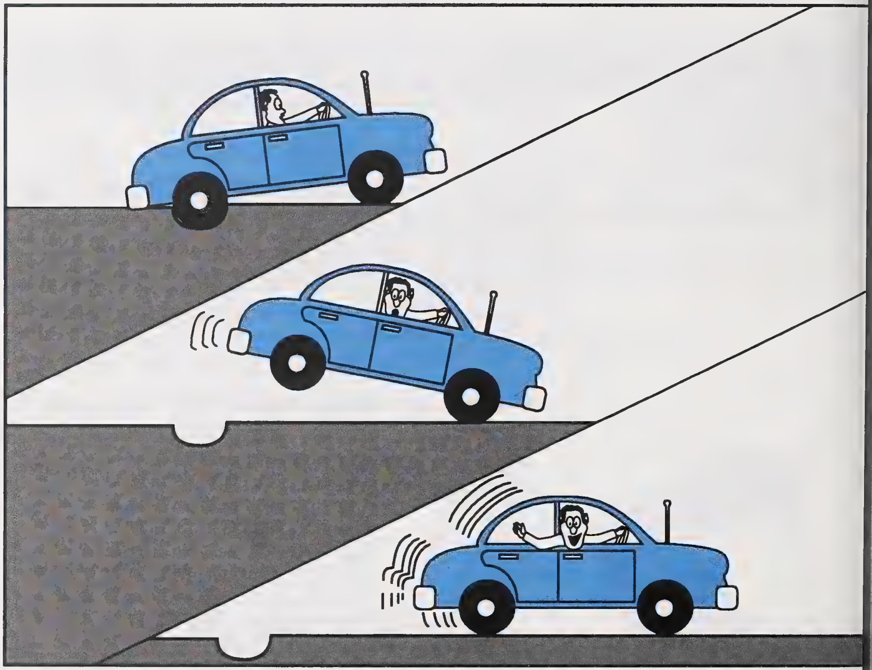
damped system – any system in which oscillations occur with decreasing amplitude over time due to frictional forces

The system you sketched on Graph B is referred to as a **damped system**. As time goes on, such a system will gradually reach a vibrational energy of zero.

Check your answers by turning to the Appendix, Section 2: Activity 4.

critically damped system – a system in which the frictional forces are adjusted to return the system to equilibrium as quickly as possible

In some systems the frictional forces involved are adjusted so that the system does not vibrate at all and immediately returns to its equilibrium position or state. This type of system is called a **critically damped system** and is of great interest to car manufacturers. The following diagram illustrates a car with insufficient damping.



2. Explain why the driver of the car in the previous diagram would like to have his car be a critically damped system.

3. Imagine that you and a friend are driving on a snowy country road. It is late, you are tired, and the road is slippery. Suddenly the car slips into a rut and you get stuck. There is not another car around for miles. How can you and your friend get the car out of the rut?

driven system – a system in which the vibration of the system is maintained by the repeated addition of a force

For any physical system to be able to vibrate for an extended period of time, the energy lost to frictional sources has to be replaced. Otherwise the system will come to halt. A system in which energy is added to maintain a vibration is called a **driven system**. Touching the accelerator to keep the car moving back and forth to get out of a rut makes the car a driven system.

resonance – The driving force of a system is applied at a frequency which matches the natural frequency of vibration of the system.

In Activity 1 you learned about an effect called **resonance**, in which the frequency of the force added to a system to increase its energy matches the natural frequency of vibration of the system.

When you gently push on the accelerator and then release it as the car is being rocked back and forth, you are using resonance to free the car.

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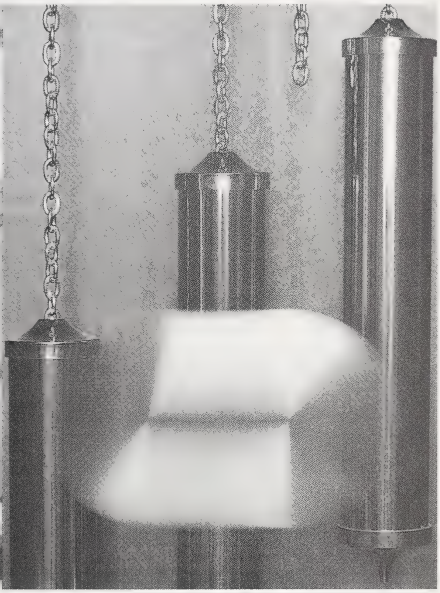

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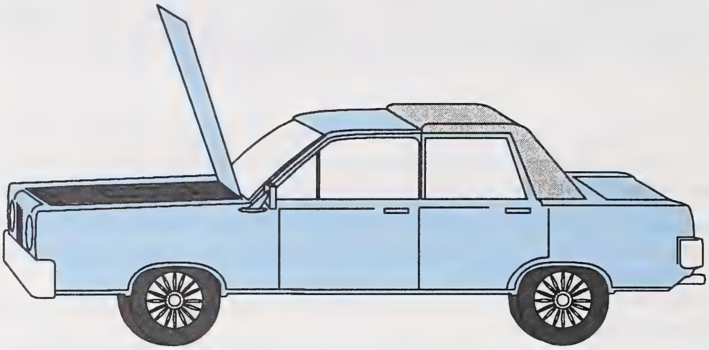
4. Automobiles are good examples of systems in which resonance effects occur. Circle the parts of the car that are likely to experience resonance. Why did you choose those parts?



Humans also have a natural frequency of vibration. Your whole body has a natural frequency of 6 Hz, while your head tends to vibrate at 20 Hz relative to your shoulders. Unfortunately, if you have to work around trucks or other heavy machinery you may be subjected to vibrations that match your body's natural frequencies. Excessive vibrations can cause changes in your circulatory and nervous systems, as well as impair your vision and coordination. People who operate this type of machinery can be protected from vibrations above 20 Hz with cushioned seats, but vibrations below 20 Hz often require specially designed seats with their own built-in shock absorbers.

5. Most tractors and large trucks tend to have a natural frequency of vibration between 1 Hz and 7 Hz.
    a. What is significant about this frequency range?
    b. Why is a properly designed seat an important safety factor for the operator and the others working beside this equipment?
    c. Farmers often stand on their farm machinery while it's operating. Why do they keep their legs slightly bent while doing this?

6. Skim through this module booklet to identify all the new equations that have been introduced. Record these new equations on the same summary sheet that you have been using for the whole course.

Check your answers by turning to the Appendix, Section 2: Activity 4.

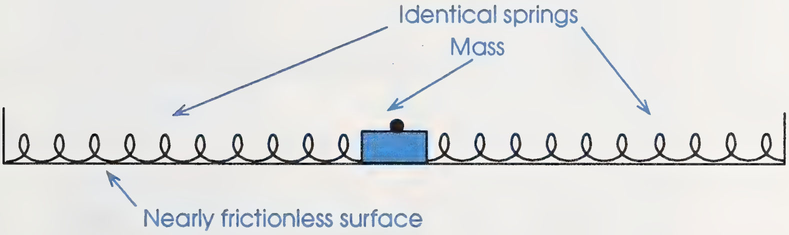
Resonances in automobiles and other machines are usually unwanted and annoying. In musical instruments, resonance is responsible for a tiny vibration being turned into enough sound to fill an entire concert hall. These forms of resonance can be very enjoyable. You will learn more about musical instruments in the next module.

Follow-up Activities

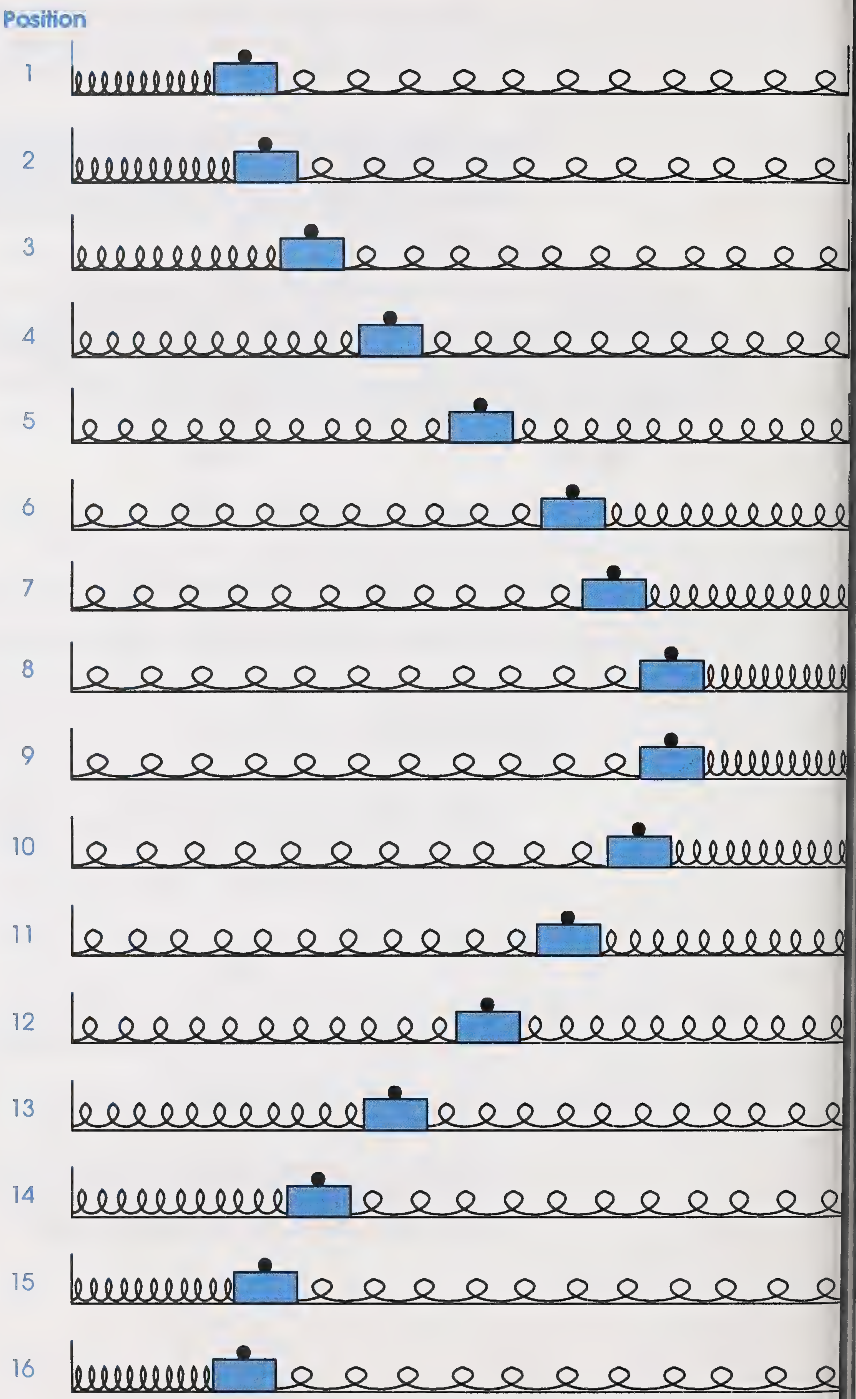
If you had difficulties understanding the concepts in the activities, it is recommended that you do the Extra Help. If you have a clear understanding of the concepts, it is recommended that you do the Enrichment.

Extra Help

1. A mass sits on a surface that is nearly frictionless. The mass has one identical spring on each side to hold it in place.



Imagine that the mass is pulled to the left and then released. The mass would vibrate back and forth through a series of positions. These positions are shown on the following page.


Position

a. When would the mass be in equilibrium? Explain.

b. Carefully draw the equilibrium point for positions 1 through 16 on the diagram. Use a ruler.

c. Draw an arrow at position 16 to show the amplitude of the vibrations for the mass.

d. Use a ruler to measure the amplitude at position 16.

e. The mass was observed to move from position 1 through to position 16 in only 2.4 s. What is the period and frequency of the vibrations for the mass?

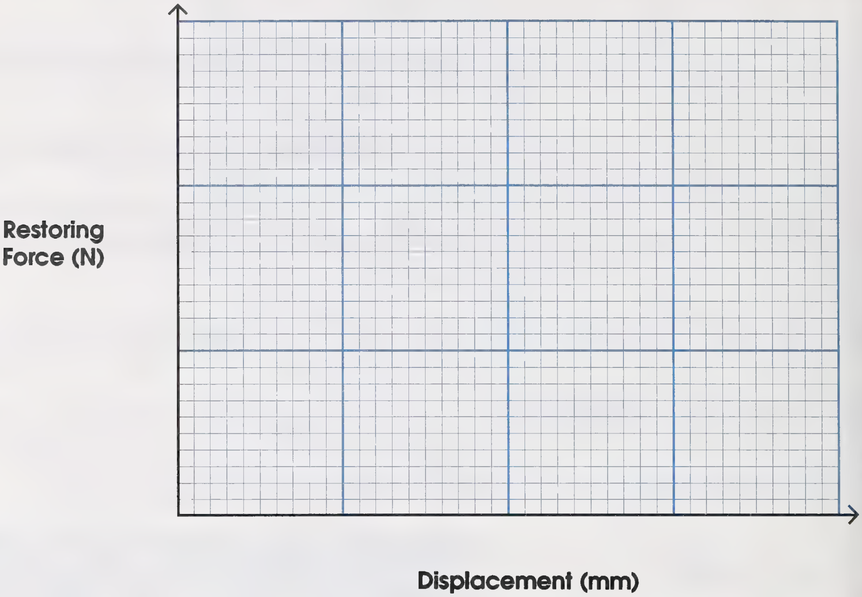
f. Draw vectors on the diagram to represent the restoring force for positions 5 through 12. Briefly explain your reasoning.

g. Measure the displacement of the centre of the mass from the equilibrium point for positions 5 through 12. Record the measurements on the following chart.

Position and Restoring Force for the Mass

Position	Displacement (mm)	Restoring force (N)
5		5
6		34
7		46
8		64
9		64
10		54
11		31
12		7

h. Use the chart to plot a graph of restoring force versus displacement for the mass. Draw the best fit line for the points on the graph.



i. Does the mass exhibit simple harmonic motion? Explain by referring to the graph.

j. In what positions does this system have its maximum potential energy? Explain.

k. In what positions does the mass have its maximum kinetic energy? Explain.

l. Draw a smooth curve to connect the centres of the masses for positions 1 through 16. How would you describe this curve?

Check your answers by turning to the Appendix, Section 2: Extra Help.

Enrichment

Chose **one** of the following activities.

1. The investigation which follows requires you to determine the elastic constant for a spring using two different methods.

Science Skills

☐ **A. Initiating**
☑ **B. Collecting**
☐ **C. Organizing**
☑ **D. Analysing**
☑ **E. Synthesizing**
☑ **F. Evaluating**

Problem

Compare the results of two independent measurements of the elastic constant of a spring using Hooke's law and simple harmonic motion.

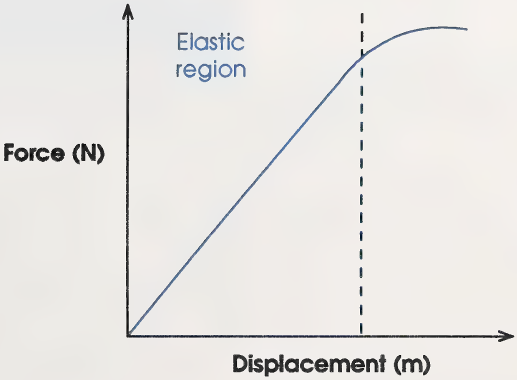
Materials

You will need the following materials for this investigation:

- retort stand and base
- stopwatch
- weight set
- a spring
- utility clamps and C-clamps
- metre stick

Background Information

In Science 10 you investigated the energy stored in a objects due to their elastic nature. A graph of force versus displacement was produced and used to find the work done in creating that displacement of the elastic object. You may have stretched an elastic band or a spring and then found the area under the curve. In this investigation the same type of graph will be put to a different use.



You will use a spring to produce similar results, only now the focus will be on the slope of the graph.

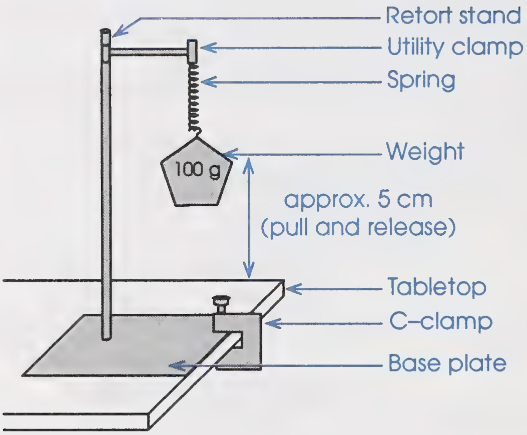
Hooke derived the formula $F = kx$ to describe the elastic region of the spring.

x = displacement of the spring from its equilibrium position
k = elastic constant of the spring

Procedure (Method A)

Note: You must do both Method A and Method B.

Prepare the retort stand as shown in the diagram.



a. Add a 100-g mass to the spring. Measure the resultant displacement of the mass from its equilibrium point. Repeat this step using 200 g, 300 g, 400 g, and 500 g. Record the measurements in the data chart.

Data for Elastic Constant

Mass (kg)	Weight (N)	Displacement (m)	k_A (N/m)

b. Calculate the *k* value (k_A) using the equation $F = kx$. Record these values in the chart.

Procedure (Method B)

Use the same apparatus as in Method A.

c. Add a 100-g mass to the spring. Pull the mass down approximately 5 cm and release it. Measure the time required to complete ten oscillations. Repeat this step using 200 g, 300 g, 400 g, and 500 g. Record the measurements in the data chart.

Data for Elastic Constant

Mass (kg)	Weight (N)	Time for Ten Oscillations (s)	Period (s)	k_B (N/m)

d. Calculate k_B using the equation $T = 2\pi\sqrt{\frac{m}{k}}$. Record the values in the chart.

Analysis

e. Find the average *k* value for the values obtained in Methods A and B. Then find the percent difference between the two average values. Account for the difference between the values.

$$\text{percent difference} = \frac{k_{A_{ave}} - k_{B_{ave}}}{k_{A_{ave}}} \times 100\%$$

2. Imagine that you are given the following systems which exhibit oscillatory motion.

   - a marble placed inside a stainless steel mixing bowl
   - a mass attached to the end of a light aluminum rod
   - a mass attached to one end of a hacksaw blade which is fixed to a benchtop

   You are asked to chose **one** system and determine if it exhibits simple harmonic motion.

   a. For one of the systems listed, list the variables which could be controlled if you were to do a study of the system's periodic motion.

   b. State the measurements that you would make and how you would use those measurements in your study.

3. This activity requires you to have access to the laser videodisc entitled *Physics: Cinema Classics* and a laser videodisc player. The activity has been written so that you can access the segments with a bar code reader. If your laser videodisc player does not have a bar code reader, use the frame numbers printed in the icon to access and play the segments.

   Place Side B of the laser videodisc in the player and press "play" to spin the disc. Use the bar code reader to view the segment explaining the experimental setup.

   Frames 25510 – 26307

   a. What will the pattern on the glass represent?

Use the bar code reader to view the segment of the glass moving by the pen.

Frames 26308 – 26595

b. How many oscillations of the pen are represented on the glass?

Use the bar code reader to view the segment of the glass being set down to be analysed.

Frames 26596 – 27016

c. What kind of motion does the pattern on the glass represent?

The pattern on the glass is going to be analysed to obtain a velocity versus time graph and an acceleration versus time graph from the original trace.

Frame 27017

Frame 27018

Frame 27019

Frame 27020

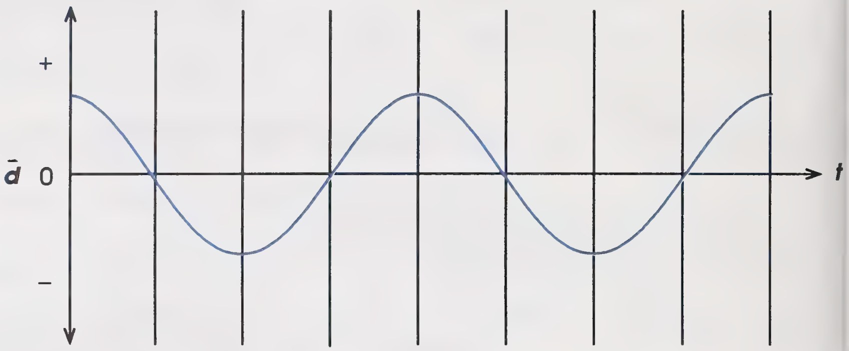
Frame 27021

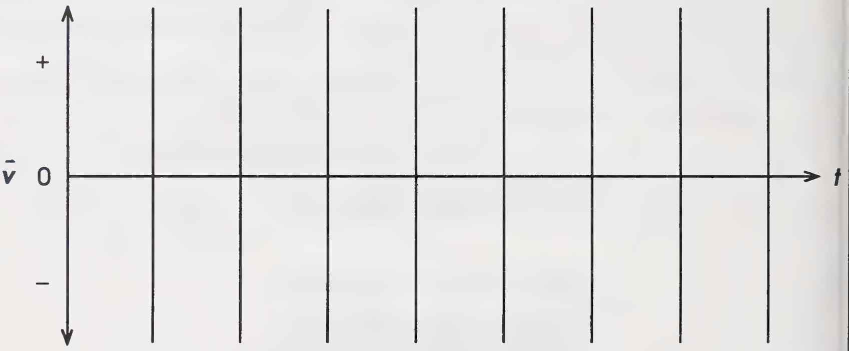
Frame 27022

Frame 27023

Use the bar code reader to watch each frame describing the process of producing the graph.

d. As you watch each frame, follow the process by producing your own velocity versus time graph.



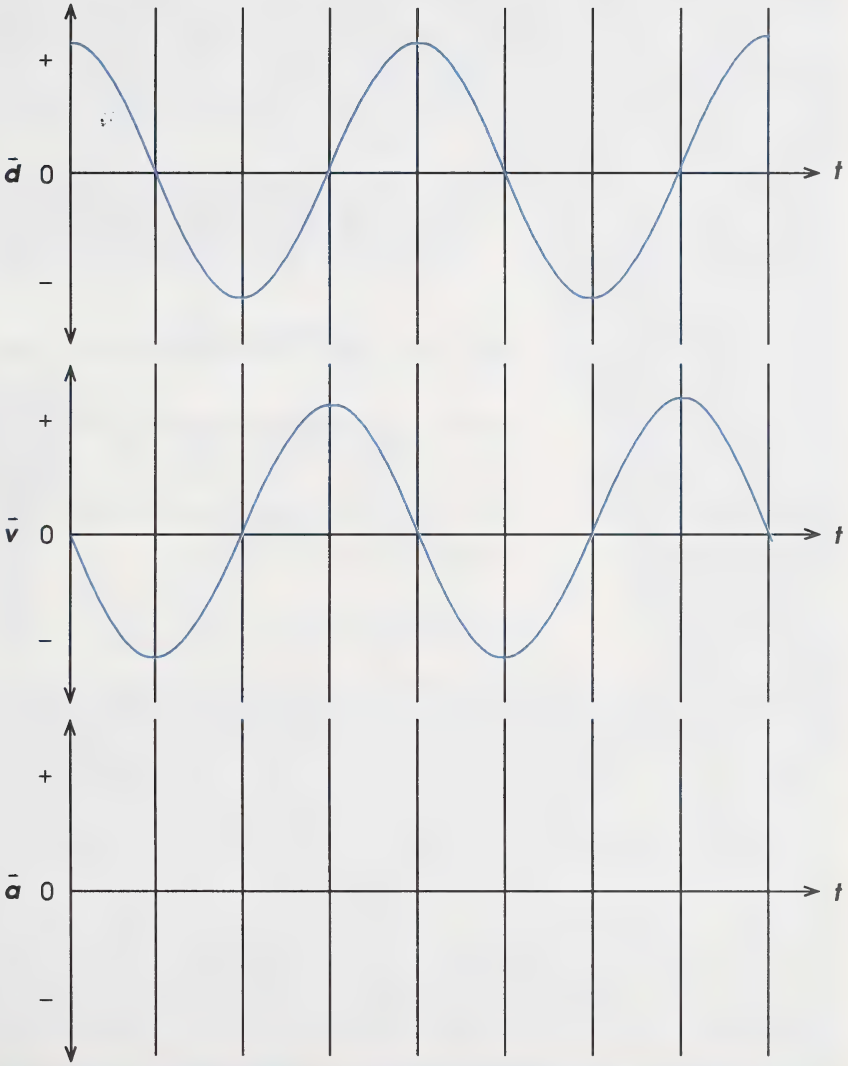


Use the bar code reader to learn how to produce the acceleration versus time graph.

Frame 27024

Frame 27025

e. Use the techniques that you have developed to produce an acceleration versus time graph.



Check your answers by turning to the Appendix, Section 2: Enrichment.

Conclusion

In this section you have looked at the concept of simple harmonic motion an the way in which it relates to the concept of energy. You have observed the harmonic motion of a simple pendulum and have looked at the way in whic harmonic motion concerns your daily life. In Module 5 you will begin to loo at how simple harmonic motion relates to energy and the movement of energy through space.

Assignment Booklet

ASSIGNMENT

Turn to your Assignment Booklet and do the assignment for Section 2.

MODULE SUMMARY

In this module you have been able to review and reinterpret the meanings of work and energy from your previous studies in Science 10. You have also seen how energy is involved with simple harmonic motion. Simple harmoni motion forms a bridge between the study of work and energy and the study of waves, sound, and light.

Appendix

- Glossary
- Activities
- Extra Help
- Enrichment

Glossary

closed system – The objects which comprise the system are isolated from outside forces.

critically damped system – a system in which the frictional forces are adjusted to return the system to equilibrium as quickly as possible

damped system – any system in which oscillations occur with decreasing amplitude over time due to frictional forces

driven system – a system in which the vibration of the system is maintained by the repeated addition of a force

energy – the capacity of an object to create a disturbance within that object or its immediate surroundings

frequency – the number of vibrations or cycles per second

kinetic energy – the energy possessed by an object which is in motion

period – the length of time for an object to complete one vibration or oscillation

potential energy – the energy stored in an object due to its location or shape

power – the rate at which energy is moved between two objects or systems

resonance – The driving force of a system is applied at a frequency which matches the natural frequency of vibration of the system.

restoring force – the force supplied to an oscillating mass which causes it to return to its equilibrium position

simple harmonic motion – the motion exhibited by any vibrating system in which the force which restores the system to its equilibrium position is a linear function of the system's displacement

work – the mathematical product of force and displacement

Suggested Answers

Section 1: Activity 1

1. You probably answered that it requires work to hold your arm in this position because you get tired holding your arm up.

2. The amount of work done is the same regardless of the length of time your arm is held in this position. In both cases the work is zero! Work is only done if the applied force creates motion in the direction of the force.

3. Textbook question 1:

   The amount of work done in each case is equal.

$$\begin{aligned} W &= Fd \\ &= (420\ \text{N})(200\ \text{m}) \\ &= 8.40 \times 10^{4}\ \text{N} \bullet \text{m} \\ &= 8.40 \times 10^{4}\ \text{J} \end{aligned} \qquad \begin{aligned} W &= Fd \\ &= (210\ \text{N})(400\ \text{m}) \\ &= 8.40 \times 10^{4}\ \text{N} \bullet \text{m} \\ &= 8.40 \times 10^{4}\ \text{J} \end{aligned}$$

Section 1: Activity 2

1. Textbook question 1:

$$\begin{aligned} W &= Fd \\ &= (80\ \text{N})(10\ \text{m}) \\ &= 800\ \text{N} \bullet \text{m} \\ &= 8.0 \times 10^{2}\ \text{J} \end{aligned}$$

Textbook question 2:

$$\begin{aligned} W &= Fd \\ &= mgd \\ &= (150\ \text{kg})(9.80\ \text{m/s}^{2})(8.0\ \text{m}) \\ &= 11\ 760\ \text{N} \bullet \text{m} \\ &= 1.2 \times 10^{4}\ \text{J} \end{aligned}$$

Textbook question 4:

$$\begin{aligned}\text{mass}_{(\text{soil})} &= (\text{density})(\text{volume})\\ &= (2.00\times10^{3}\ \text{kg/m}^{3})(1.15\ \text{m}^{3})\\ &= 2.30\times10^{3}\ \text{kg}\end{aligned}$$

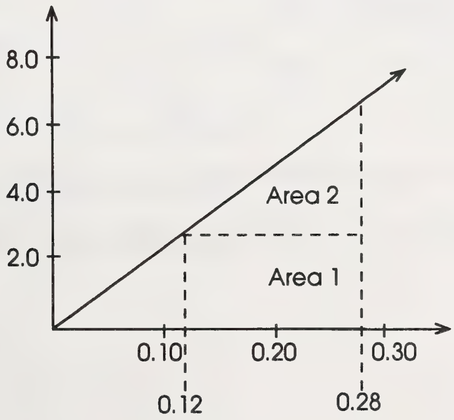
$$\begin{aligned}F_{(\text{soil})} &= mg\\ &= (2.30\times10^{3}\ \text{kg})(9.80\ \text{m/s}^{2})\\ &= 2.254\times10^{4}\ \text{N}\end{aligned}$$

$$\begin{aligned}F_{(\text{total})} &= F_{(\text{bucket})} + F_{(\text{soil})}\\ &= (2.25\times10^{3}\ \text{N}) + (2.254\times10^{4}\ \text{N})\\ &= 2.479\times10^{4}\ \text{N}\end{aligned}$$

$$\begin{aligned}W &= Fd\\ &= (2.479\times10^{4}\ \text{N})(7.50\ \text{m})\\ &= 1.86\times10^{5}\ \text{J}\end{aligned}$$

Textbook question 5:

$$\begin{aligned}W &= \text{area under curve}\\ &= \text{Area 1} + \text{Area 2}\\ &= bh + \frac{1}{2}bh\\ &= (0.16\ \text{m})(3.0\ \text{N}) + \frac{1}{2}(0.16\ \text{m})(4.0\ \text{N})\\ &= 0.48\ \text{J} + 0.32\ \text{J}\\ &= 0.64\ \text{J}\end{aligned}$$



2. These problems are answered on page 671 of your textbook.

3. Worker A and Worker B have done the same amount of work! Time is not a factor of work. Only the applied force and the distance over which that force is applied affect work.

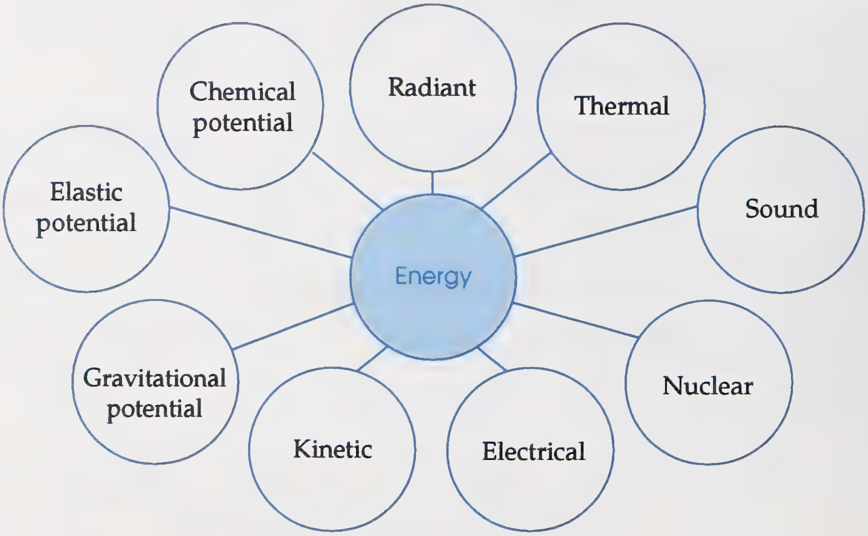
4. These problems are answered on page 671 of your textbook.

5. $F = 325\text{ N}$
$v = 1.8\text{ m/s}$
$P = ?$

$$\begin{aligned} P &= Fv \\ &= (325\text{ N})(1.8\text{ m/s}) \\ &= 585\text{ N} \bullet \text{m/s} \\ &= 5.9 \times 10^{2}\text{ W} \end{aligned}$$

Section 1: Activity 3

1. This is a sample answer. The order in which the types are listed is not important. You should have been able to list at least half of the energy types shown.



2. This question is answered on page 672 of your textbook.

3. These questions are answered on page 673 of your textbook.

4. Textbook question 14:

$$\begin{aligned}\Delta E_p &= E_{p_f} - E_{p_i}\\ &= (500\ \text{N})(-5.50\ \text{m}) - (500\ \text{N})(0.00\ \text{m})\\ &= -2.75 \times 10^3\ \text{J}\end{aligned}$$

5. The negative sign indicates the location of the reference level, which is above where Mary stopped.

Section 1: Activity 4

1. The following results show the calculation techniques. The data used was from Part B.

$$\text{period} = \frac{\text{time}}{\text{number of dots}} = \frac{2.00\ \text{s}}{173\ \text{dots}} = 0.0116\ \text{s/dot}$$

2. See the sample calculation for question 1. It shows the correct answer.

3. The following sample calculations are based on the sample data provided for Part B.

Data for Pendulum Investigation							
	Data for Maximum E_k				Data for Maximum E_p		
Trial	**Distance (m)**	**Time (s)**	**Maximum Speed (m/s)**	**Maximum Kinetic Energy (J)**	**Release Height (m)**	**Maximum Potential Energy (J)**	**Percent Difference (%)**
1	0.088	0.116	0.759	0.14	0.030	0.15	−6.7
2	0.121	0.116	1.04	0.27	0.050	0.25	+8.0
3	0.176	0.116	1.52	0.58	0.100	0.49	+18

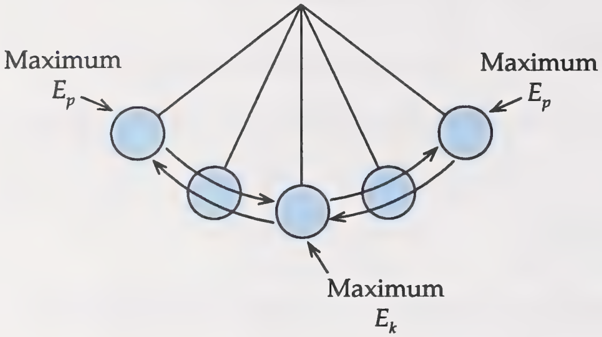
4. See the data chart for calculated values.

5. See the data chart for calculated values.

6. See the data chart for calculated values.

7. A shorter pendulum will swing faster. Since the pendulum will be moving faster, the dots on the ticker tape may be very close together or even run into each other. Having a longer pendulum will eliminate these problems.

8.



9. Answers will vary according to results.

   - If a low percent difference is obtained (15% or less), you should agree with the statement since the experiment incorporates at least 15% error due to measurement.

   - A high percent difference would lead you to suspect that either the results you have obtained are questionable or the statement is false.

10. The greatest source of error is probably the measurement of distance and the calculation of speed from the ticker tape. To reduce this error, it would be necessary to have a way of measuring the speed of the pendulum bob at the lowest point of the swing. You may suggest using a photogate timer or radar gun as a means of measuring speed.

Section 1: Follow-up Activities

Extra Help

1.

Summary Chart for Work and Energy

Term	Meaning	Symbol	SI Units	Equation(s)
Work	• Work is the product of a force on an object and the distance the object moves in the direction of the force. • Work is a direct measure of the amount of energy transferred from one object to another.	W	N•m or J	$W = Fd$ $W = Fd(\cos\theta)$
Energy	• Energy is the capability to produce any change within a system. • When work is done **by** an object, it loses energy. • When work is done **to** an object, it gains energy.	E	J	
Kinetic Energy	Kinetic energy is energy of motion.	E_k	J	$E_k = \frac{1}{2}mv^2$
Potential Energy	Potential energy is energy stored due to an object's position or condition.	E_p	J	For gravity: $E_p = mgh$
Power	Power is the rate of doing work or the rate of consuming energy.	P	W	$P = \frac{W}{t}$ $P = \frac{E}{t}$

2. Textbook question 1:

   The truck would have more kinetic energy. Kinetic energy varies directly with the mass ($E_k \propto m$).

   Textbook question 4:

   Yes, it is possible to apply a force and not change the kinetic energy. If you apply a force and the object does not move, no work is done. The kinetic energy would not change. Another possibility would be if the force and the distance were not in the same direction. In uniform circular motion, the centripetal force acts continually, but there is no change in kinetic energy.

3. Textbook question 7:

   Yes. For the ball to have both potential and kinetic energy, the ball must be moving at some height above your reference level.

4. Textbook question 22. a.:

   First you must calculate how much work is done pulling the string back.

$$\begin{aligned} W &= Fd \\ &= (201\ \text{N})(1.3\ \text{m}) \\ &= 261.3\ \text{J} \\ &= 2.6 \times 10^2\ \text{J} \end{aligned}$$

$$W = \Delta E_k = \frac{1}{2}mv_f^{\ 2} - \frac{1}{2}mv_i^{\ 2}$$

$$\Delta E_k = \frac{1}{2}m(v_f)^2$$

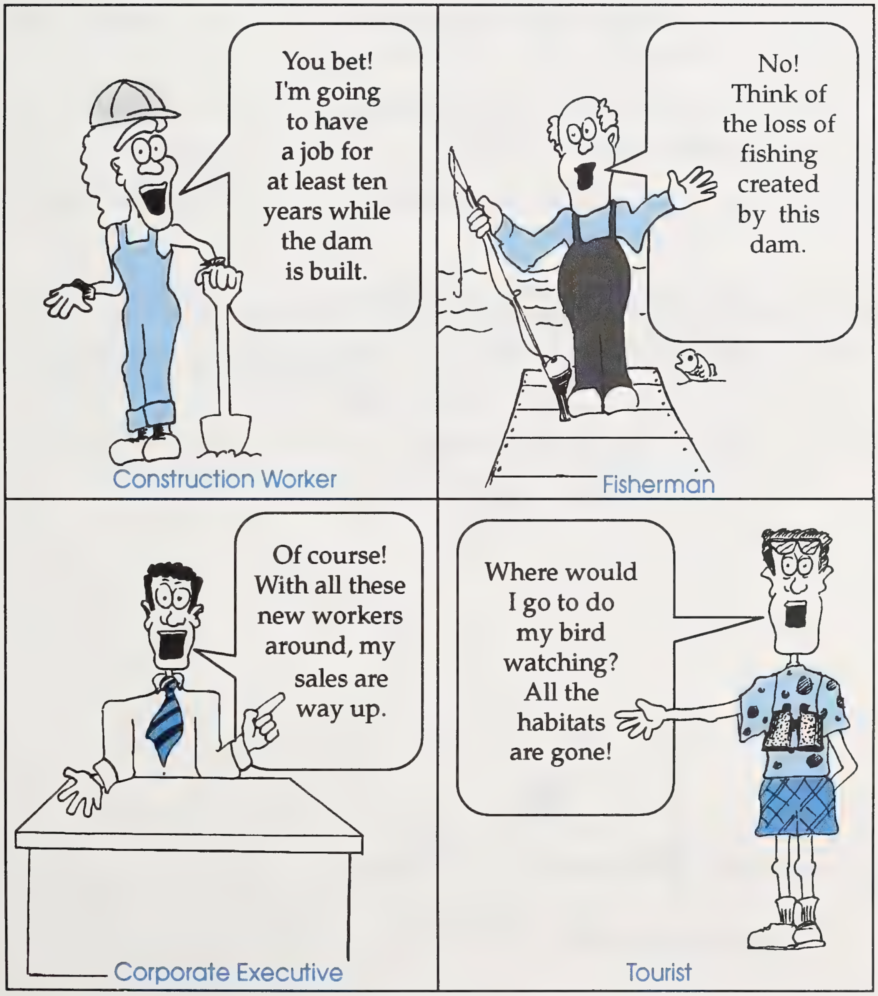
$$\begin{aligned} v_f &= \sqrt{\frac{2\Delta E_k}{m}} \\ &= \sqrt{\frac{2(261.3\ \text{J})}{0.30\ \text{kg}}} \\ &= \sqrt{1742\ \text{m}^2/\text{s}^2} \\ &= 42\ \text{m/s} \end{aligned}$$

Textbook question 22. b.:

$$\begin{aligned}\Delta E_p &= W\\ mg\Delta h &= W\\ \Delta h &= \frac{W}{mg}\\ &= \frac{261.3\ \text{J}}{(0.30\ \text{kg})(9.80\ \text{m/s}^2)}\\ &= 89\ \text{m}\end{aligned}$$

Enrichment

1. Your answers may vary from those shown.


You bet! I'm going to have a job for at least ten years while the dam is built.
Construction Worker
No! Think of the loss of fishing created by this dam.
Fisherman
Of course! With all these new workers around, my sales are way up.
Corporate Executive
Where would I go to do my bird watching? All the habitats are gone!
Tourist

2. James Prescott Joule (1818-1889) was an English physicist who studied heat and electrical energy. Joule's early years were spent working as a brewer, and along the way he noticed the correlation between stirring a liquid and the heating of that liquid. Joule performed a number of experiments that were critical to the present view of heat as a form of energy and the transfer of heat as a transfer of energy. Joule found that work was always equal to a specific amount of heat. In honour of his contributions to the understanding of work and energy, the unit for work and energy is named the joule (J).

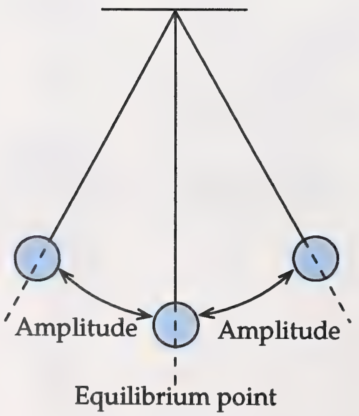
3. Answers to this activity can be found at the back of the booklet on Critical Thinking which comes with the teacher resource package for your textbook.

Section 2: Activity 1

1.

	Column A	Column B
e	the maximum amount of displacement in a vibratory (oscillatory) motion	a. stable system
d	the number of oscillations or vibrations completed in some fixed time	b. period
b	the time required to complete one vibration or oscillation	c. resonance
c	The application of the displacing force on a system matches the natural frequency of that system.	d. frequency
		e. amplitude
a	A disturbance creates a restoring force and the restoring force causes the system to overshoot the equilibrium point, which causes a restoring force...	

2.



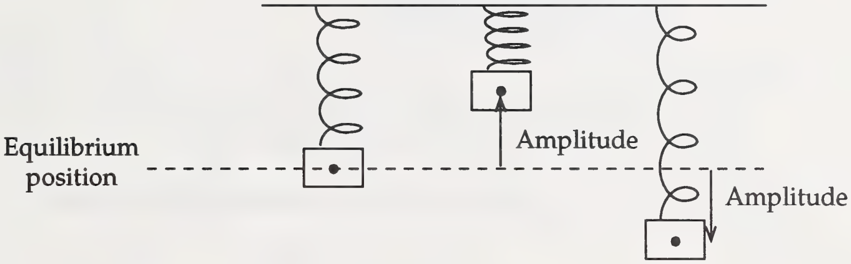
3. Galileo found that the period of a pendulum was constant regardless of the angle or displacement.

4. Because the period of a pendulum is a constant, it could be used as a means of marking consistent time intervals. Up until Galileo's discovery, there was no consistent method for measuring time.

5. An object is said to experience simple harmonic motion if the restoring force that returns it to the equilibrium position is directly proportional to the displacement.

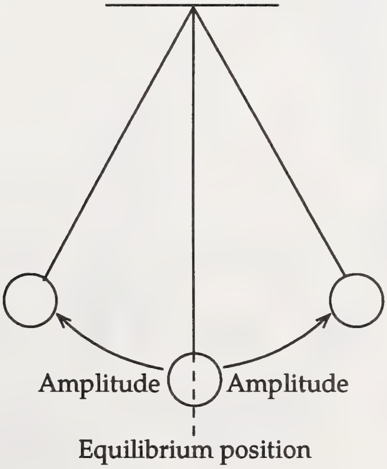
6. To measure the period of the mass on the spring, you would need to time one complete oscillation. An example would be to find the time for the mass to move from the bottom to the top and back to the bottom again.

7. The amplitude is the maximum displacement from the equilibrium position.



8. The period of a pendulum is the time required for the pendulum to complete one oscillation. You could measure the period by finding the time for the pendulum to move from the far left to the far right and back to the far left again.

9. The amplitude is the maximum displacement from the equilibrium position.



10. Any of the examples listed on the top of page 150 in the textbook would be acceptable. The most common example is the swing.

11. Answers are given in the chart following question 12.

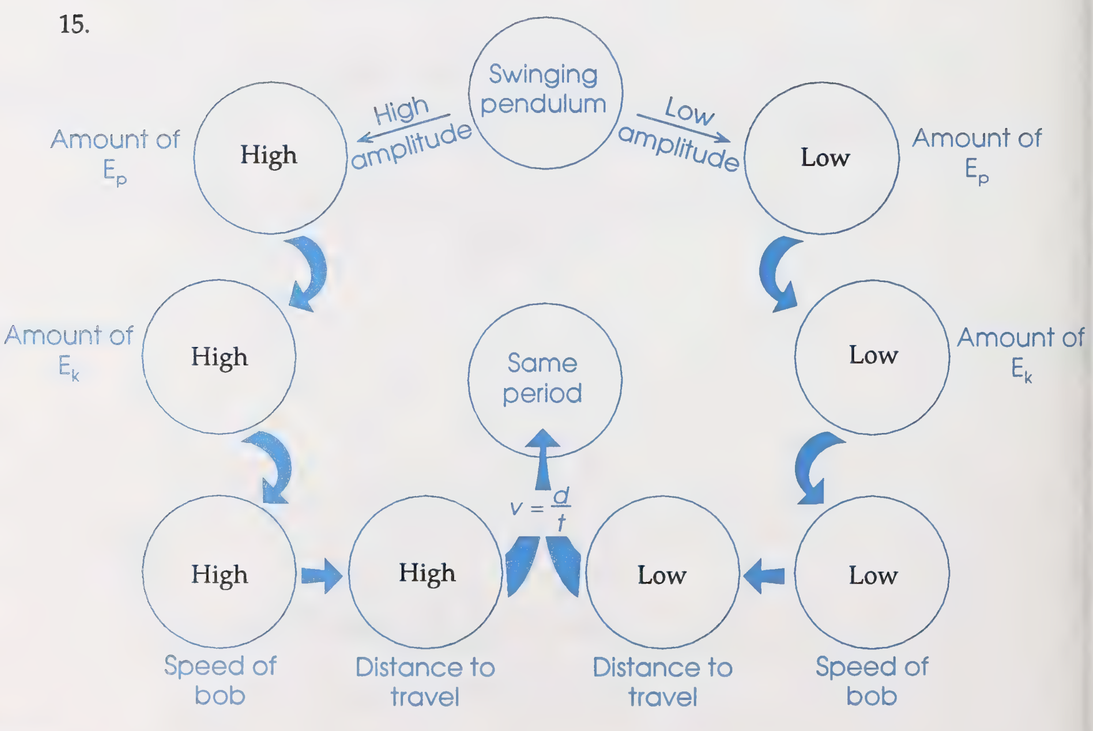
12. Answers are given in the following chart.

Release Angle (°)	**Time for Ten Swings (s)**	**Period (s)**
5°	14.19	1.42
10°	14.18	1.42
30°	14.19	1.42
60°	14.19	1.42

13. Answers are shown in the chart following question 12. The data represents one set of possible results. Although the times that you measure may not be the same as these times, your values should all be close to each other.

14. The period is the same no matter what release angle was used.

15.



16. To move from the far left to the far right is only half a vibration for the pendulum. You must calculate the period for one complete vibration.

$$\frac{1}{2}T = 0.75\ \text{s}$$
$$T = 1.5\ \text{s}$$

17. $$f = \frac{3930\ \text{cycles}}{15\ \text{s}}$$
$$= 262\ \text{Hz}$$

18. $$f = \frac{1\,200\,000\ \text{cycles}}{1.0\ \text{min}}$$
$$= \frac{1\,200\,000\ \text{cycles}}{60\ \text{s}}$$
$$= 20\,000\ \text{Hz}$$
$$= 2.0 \times 10^4\ \text{Hz}$$

19.

Calculating Period and Frequency

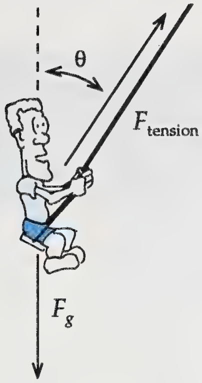
Object Vibrating	Number of Vibrations	Total Time for Vibrations	Calculation of Period (s)	Calculation of Frequency (Hz)
Person on Swing	60	150 s	$\frac{150\text{ s}}{60\text{ cycles}} = 2.5\text{ s}$	$\frac{60\text{ cycles}}{150\text{ s}} = 0.40\text{ Hz}$
Pendulum of a Grandfather Clock	1800	60 min	$\frac{60\text{ min}}{1800} = \frac{3600\text{ s}}{1800} = 2.0\text{ s}$	$\frac{1800\text{ cycles}}{3600\text{ s}} = 0.50\text{ Hz}$
Your Eardrum with the Lowest Pitched Sound that You Can Hear	200	10 s	$\frac{10\text{ s}}{200} = 0.05\text{ s}$	$\frac{200}{10\text{ s}} = 20\text{ Hz}$
Your Eardrum with the Highest Pitched Sound You Can Hear	20 000	1 s	$\frac{1\text{ s}}{20\,000} = 0.000\,05\text{ s}$	$\frac{20\,000}{1\text{ s}} = 20\,000\text{ Hz}$
An Electron in the Back of Your Eye Absorbing Blue Light	6.7×10^{14}	1 s	$\frac{1\text{ s}}{6.7 \times 10^{14}} = 1.5 \times 10^{-15}\text{ s}$	$\frac{6.7 \times 10^{14}}{1\text{ s}}$ $= 6.7 \times 10^{14}\text{ Hz}$

20. Period and frequency are inversely related to each other. In other words, when doing calculations, the numerator and denominator are reversed between period and frequency.

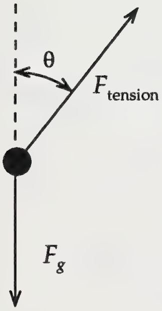
Section 2: Activity 2

1. Simple harmonic motion requires an object to vibrate around an equilibrium position. The object is forced back to the equilibrium position by a restoring force. The restoring force is directly proportional to the displacement from the equilibrium position and it acts in a direction opposite to the displacement.

2.



3.



4. $\sin\theta = \dfrac{F_{\perp}}{F_g}$

$$F_{\perp} = F_g\left(\sin\theta\right)$$

5. Answers are shown in the chart following question 6.

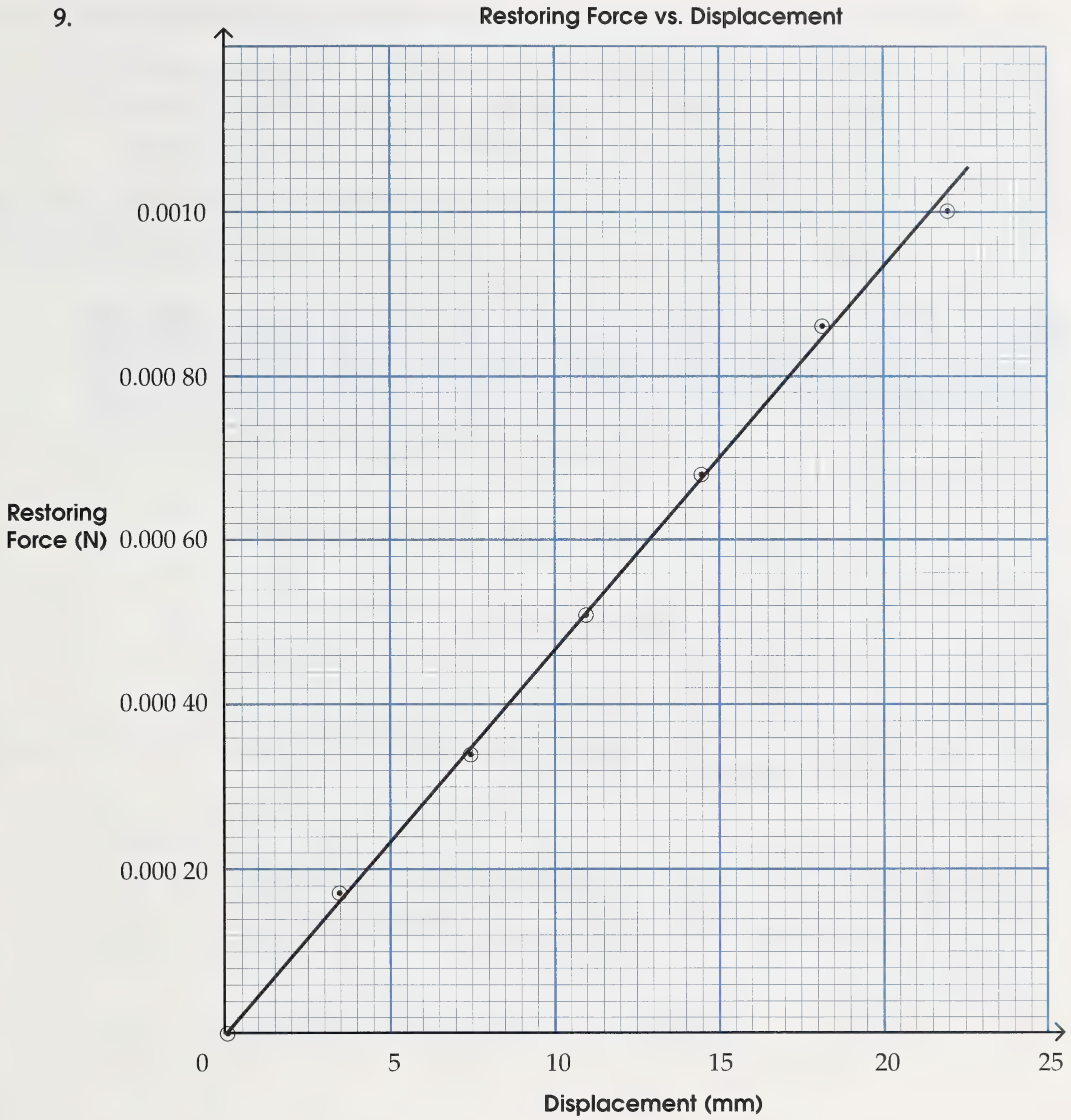
6. Answers are shown in the following chart.

Data from the Scale Diagram of a Pendulum				
Position of the Pendulum	**Angle (°)**	**Displacement (mm)**	**Restoring Force (N)**	**Acceleration (m/s^2)**
Equilibrium Point	0.0	0	0	0
1	1.0	3.5	0.000 17	0.17
2	2.0	7.5	0.000 34	0.34
3	3.0	11.0	0.000 51	0.51
4	4.0	14.5	0.000 68	0.68
5	5.0	18.2	0.000 86	0.86
6	6.0	22.0	0.0010	1.0

7. Answers are shown in the chart following question 6.

8. Answers are shown in the chart following question 6.

9.



10. The best fit line is drawn on the graph. The best fit line is a straight line.

11. This shape indicates that the restoring force varies directly with the displacement.

12. You should have predicted that the acceleration increases directly with the displacement. Because F is directly proportional to displacement and $F = ma$, acceleration is proportional to displacement since mass is constant.

13. The motion of the pendulum is simple harmonic. The restoring force varies directly with the displacement from the equilibrium position, as shown by the straight line graph. The restoring force acts opposite to the direction of the displacement and always brings the pendulum back to equilibrium.

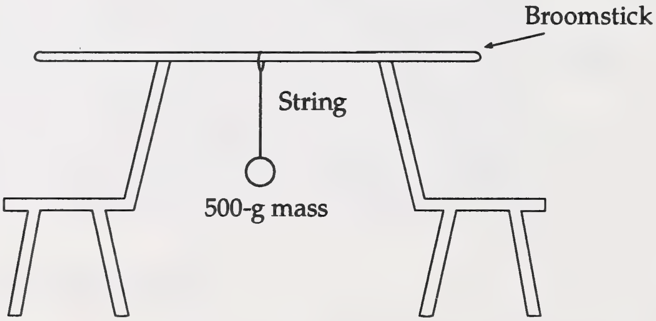
Section 2: Activity 3

Answers for this activity will vary for each design. The answers offered here are considered typical.

1. The following list of materials is given as a sample answer.

   - stopwatch
   - pendulum bob (500-g mass)
   - string
   - support stand

   You may have drawn a diagram of the experimental setup. You may have used the chair and broomstick setup again.



2. The following steps are given as an example of the procedure that you may have used.

   - Set up the apparatus as shown in the diagram.
   - Make a pendulum 30 cm long using the string and 500-g mass.
   - Move the pendulum bob 10° and release it.
   - Measure and record the time taken to complete ten oscillations.
   - Repeat the procedure using lengths of 40 cm, 50 cm, 60 cm, and 70 cm.

3. These answers are samples only. Your data chart should be set up similarly.

Length (m)	**Time for Ten Oscillations (s)**	**Actual Period (s)**	**Expected Period (s)**	**Percent Error**
0.30	10.88	1.09	1.10	0.91
0.40	11.93	1.19	1.27	6.3
0.50	13.91	1.39	1.42	3.5
0.60	14.76	1.48	1.55	4.5
0.70	16.28	1.63	1.68	3.0

Average error = 2.9%

4. The following answer is a sample only.

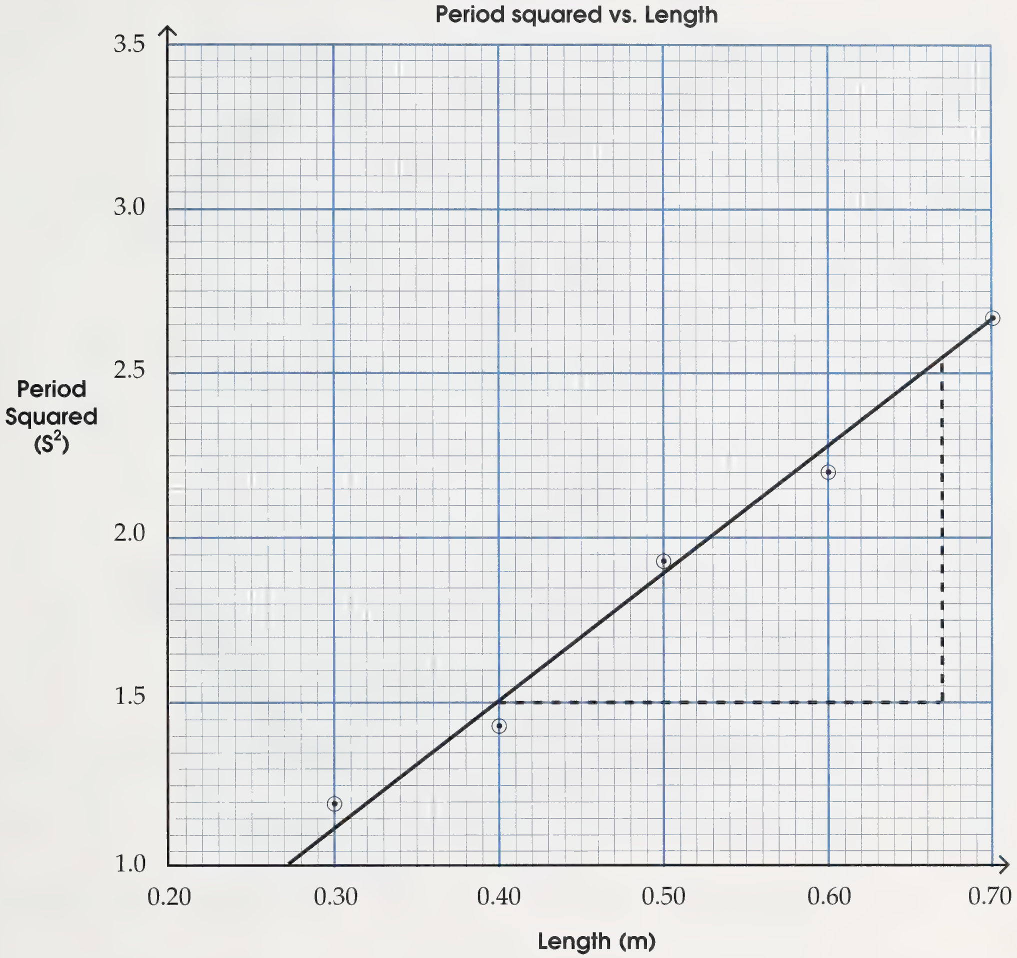
   The greatest source of error in this experiment is in construction of the pendulum. The length of the pendulum must be measured to the centre of mass of the pendulum bob. Timing may be a source of error unless you allow for ten swings and then divide by 10 to get the period.

5. Answers to this question will vary, depending on your results. If your percent error is less than ten percent, it would be reasonable to conclude that you verified the equation.

6. Answers will vary with results. This data is based on the sample answers for questions 1 to 5.

Length and Period Squared Data		
Length of Pendulum (m)	**Period of Pendulum (s)**	**Period Squared (s^2)**
0.30	1.09	1.19
0.40	1.19	1.42
0.50	1.39	1.93
0.60	1.48	2.19
0.70	1.63	2.66

7. a. This graph is a sample based on the sample data provided earlier. Note that the graph does not need to begin with zero at the origin.



b. Refer to the previous graph. The best fit line was drawn.

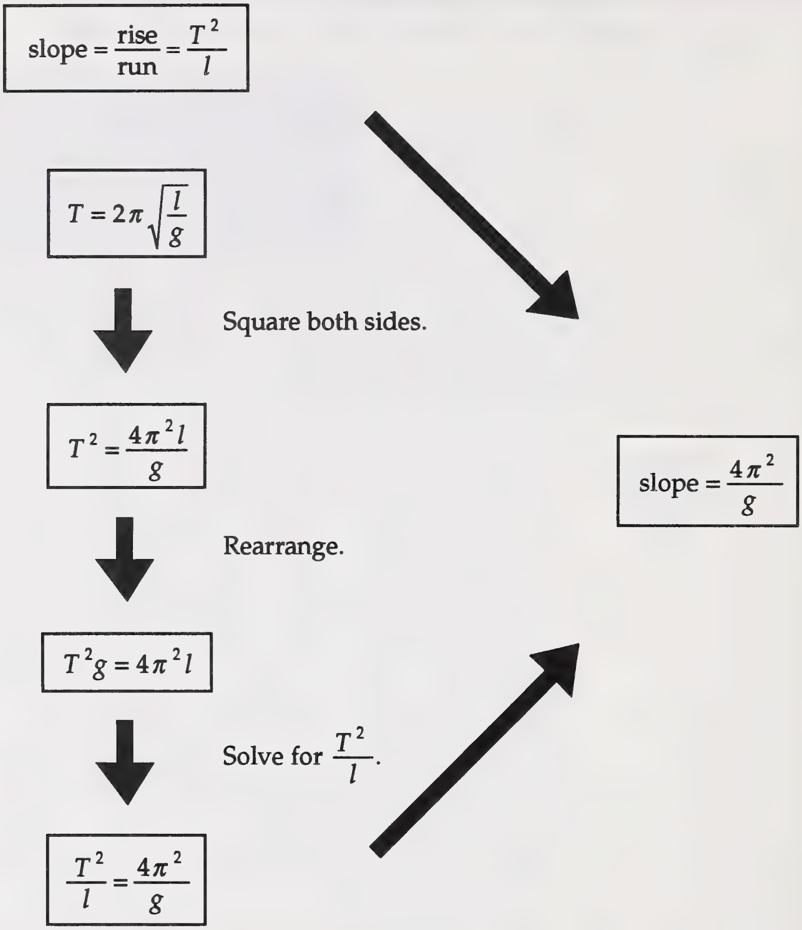
8. $$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{2.55\ \text{s}^2 - 1.50\ \text{s}^2}{0.67\ \text{m} - 0.40\ \text{m}}$$

$$= \frac{1.05\ \text{s}^2}{0.27\ \text{m}}$$

$$= 3.89\ \text{s}^2/\text{m}$$

$$= 3.9\ \text{s}^2/\text{m}$$

9.



$$\text{slope} = \frac{\text{rise}}{\text{run}} = \frac{T^2}{l}$$

$$T = 2\pi\sqrt{\frac{l}{g}}$$

Square both sides.

$$T^2 = \frac{4\pi^2 l}{g}$$

Rearrange.

$$T^2 g = 4\pi^2 l$$

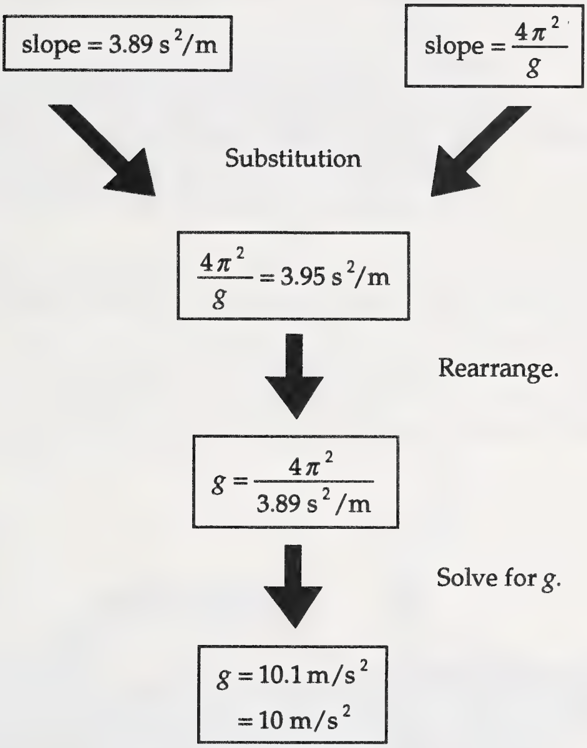
Solve for $\frac{T^2}{l}$.

$$\frac{T^2}{l} = \frac{4\pi^2}{g}$$

$$\text{slope} = \frac{4\pi^2}{g}$$

The slope represents the ratio of $4\pi^2$ divided by the acceleration due to gravity.

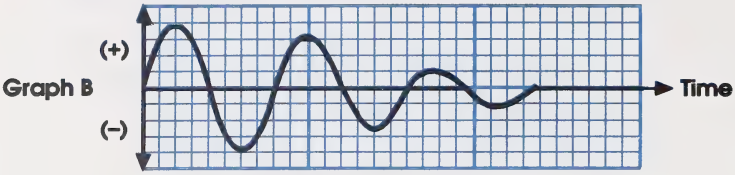
10.


$\boxed{\text{slope} = 3.89\ \text{s}^2/\text{m}}$
$\boxed{\text{slope} = \frac{4\pi^2}{g}}$
Substitution
$\boxed{\frac{4\pi^2}{g} = 3.95\ \text{s}^2/\text{m}}$
Rearrange.
$\boxed{g = \frac{4\pi^2}{3.89\ \text{s}^2/\text{m}}}$
Solve for g.
$\boxed{\begin{aligned} g &= 10.1\ \text{m/s}^2 \\ &= 10\ \text{m/s}^2 \end{aligned}}$

11.
$$\text{percent error} = \frac{|\text{experimental value} - \text{theoretical value}|}{\text{theoretical value}} \times 100\%$$
$$= \frac{|10.1\ \text{m/s}^2 - 9.80\ \text{m/s}^2|}{9.80\ \text{m/s}^2} \times 100\%$$
$$= 3.1\%$$

Section 2: Activity 4

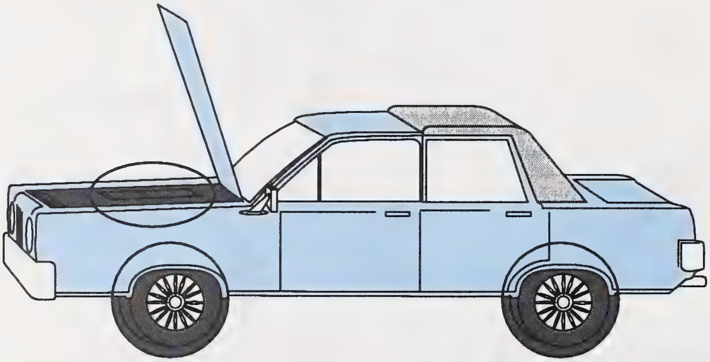
1.



2. The driver would like to enjoy the smoothest, quietest ride. To do this, the car needs to stop vibrating after it hits a bump. Shock absorbers help the car stop bouncing.

3. Have your friend rock the car back and forth by gently pushing on the accelerator for short intervals. If you push on the car in resonance with the rocking motion, the car will probably gain enough momentum and energy to escape from the rut.

4.



These parts are subject to driving forces. Any imbalance in vibration could cause resonance to occur. This is usually noticeable while accelerating from a stop to highway speeds. As the car speeds up, the wheels and the engine parts begin to turn at higher and higher frequencies. Eventually it reaches a speed at which the frequency of the moving part matches the resonant frequency of that part. If the part happens to be unbalanced, the effect of resonance may be great enough to shake the whole car. Automobile manufacturers try to avoid this by having parts that are properly balanced.

5. a. The natural frequency of vibration for the human body is 6 Hz. This is within the 1 Hz to 7 Hz range.

   b. A properly designed seat will protect the driver from the harmful effects of excessive vibration. This means that the driver will be less likely to suffer an impairment in vision or coordination and will be able to operate the machine in a way that is safer for everyone.

   c. When the legs are bent, vibrations do not pass as easily to the rest of the body. The effect is similar to standing on the pedals of your bike with your legs bent while riding down a very bumpy road.

6. The following new equations were introduced in this module.

- Energy:

$$W = Fd$$

$$W = Fd(\cos\theta)$$

$$P = \frac{W}{t}$$

$$E_k = \frac{1}{2}mv^2$$

E_p = work done to change the position or condition of an object

$E_p = mgh$ (gravitational potential energy)

- Simple Harmonic Motion:

$$T = \frac{1}{f}$$

Section 2: Follow-up Activities

Extra Help

1. a. The mass would be in equilibrium when the forces on it are equal and balanced. This would occur in the exact centre of the apparatus.

b. The answer is drawn on the diagram that follows 1. f.

c. The answer is drawn on the diagram that follows 1. f.

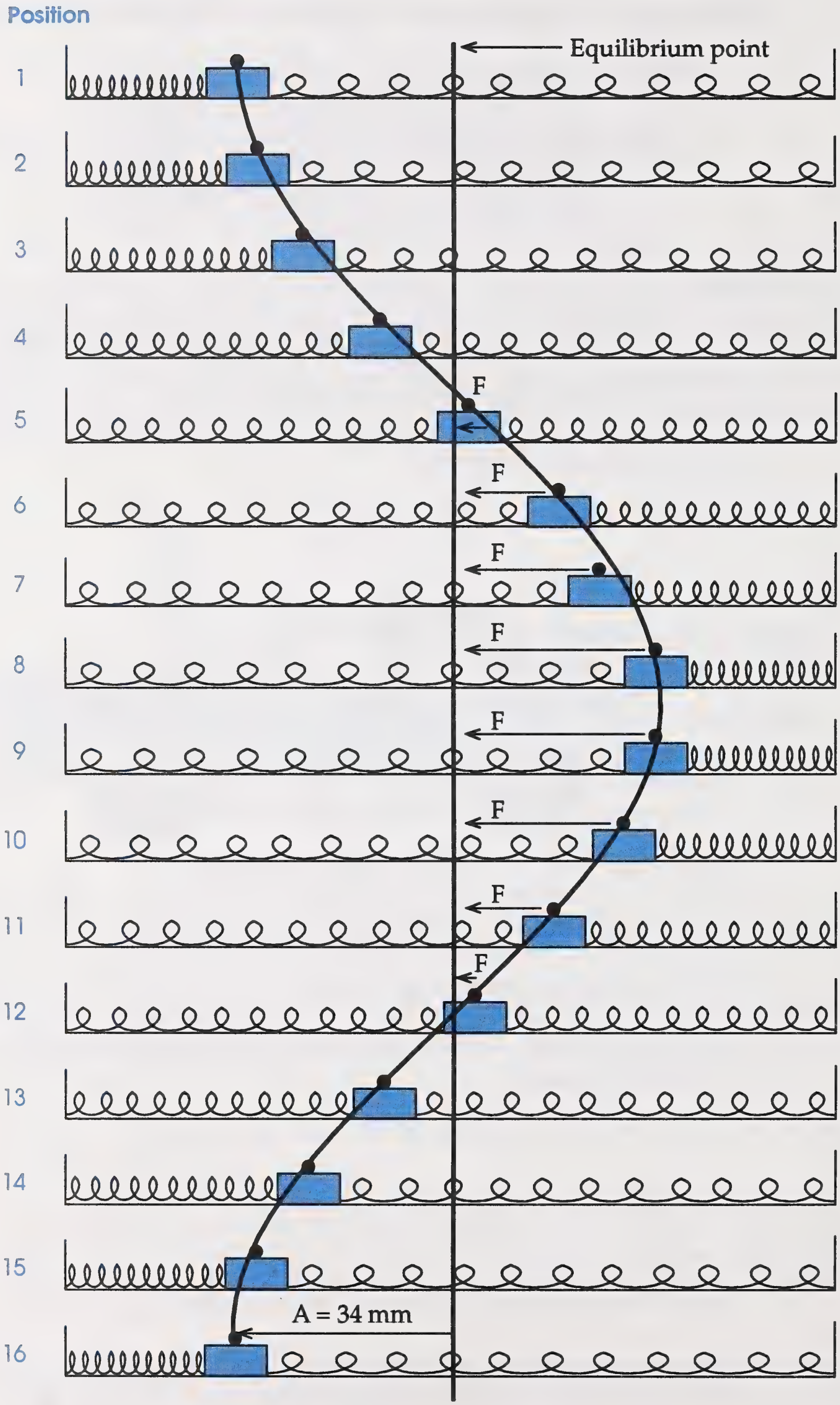
d. A = 34 mm, as measured on the diagram.

e. The period is 2.4 since positions 1 and 16 mark the beginning and the end of one complete vibration.

$$\begin{aligned} f &= \frac{1}{T} \\ &= \frac{1}{2.4\ \text{s}} \\ &= 0.42\ \text{Hz} \end{aligned}$$

f. The answers are drawn on the diagram that follows.

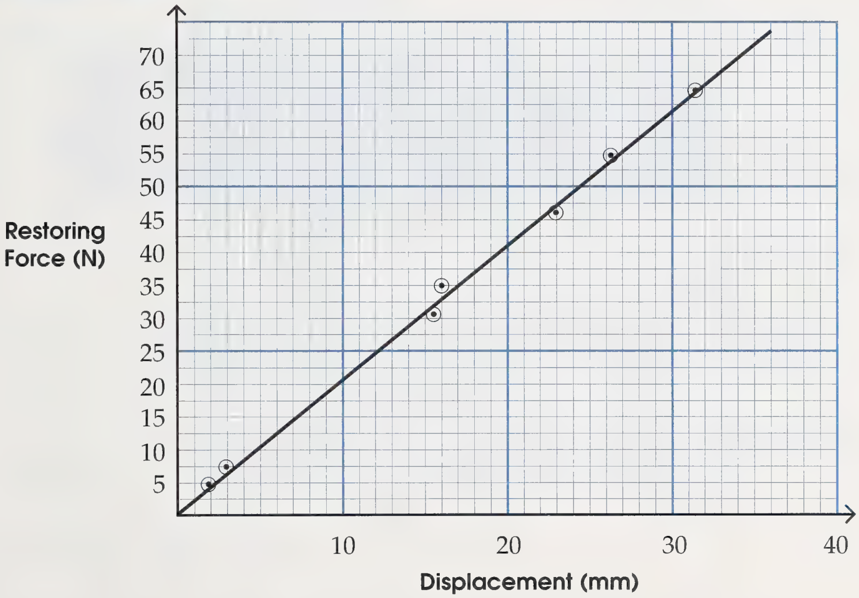
The restoring force is larger when the mass is further from the equilibrium point. This is because the springs are stretched and compressed at these locations.


Position
1
2
3
4
5
6
7
8
9
10
11
12
13
14
15
16
Equilibrium point
F
F
F
F
F
F
F
F
A = 34 mm

g.

Position and Restoring Force for the Mass		
Position	**Displacement (mm)**	**Restoring force (N)**
5	2.0	5
6	16	34
7	23	46
8	32	64
9	31.5	64
10	26.5	54
11	15.5	31
12	3.0	7

h.



i. Yes, the mass exhibits simple harmonic motion because the restoring force is directly proportional to the displacement, as shown on the straight line graph. Also notice that the restoring force for positions 5 through 12 is directed to the left, while the displacement of the mass from equilibrium is to the right. The restoring force acts in the opposite direction to the displacement.

j. The system has its maximum potential energy when the most work was done to move the mass from the equilibrium position. Since $W = Fd$, the most work was done at positions 1, 8, 9, and 16. At these places the force and distance are largest.

k. The mass has its maximum kinetic energy when it is moving with the highest speeds. This occurs at positions 5 and 12 because the potential energy is at a minimum at these locations. Since energy is conserved, the energy is converted to kinetic energy at these places.

l. The curve was drawn on the diagram of the 16 positions. The curve looks like a wave.

Enrichment

1. a. Sample results are shown in the following chart. Your results will depend on which spring you used. The sample results are not typical.

Data for Elastic Constant

Mass (kg)	Weight (N)	Displacement (m)	k_A (N/m)
0.100	0.980	0.032	30.6
0.200	1.96	0.066	29.7
0.300	2.94	0.098	30.0
0.400	3.92	0.130	30.2
0.500	4.90	0.163	30.1

average $k_A = 30.1\ \text{N/m}$

b. The values for k_A are shown in the chart.

c. Sample results are shown in the chart. Once again, these results are not typical.

Data for Elastic Constant

Mass (kg)	Weight (N)	Time for Ten Oscillations (s)	Period (s)	k_B (N/m)
0.100	0.980	3.86	0.386	26.5
0.200	1.96	5.24	0.524	28.8
0.300	2.94	5.99	0.599	33.0
0.400	3.92	7.18	0.718	30.6
0.500	4.90	7.98	0.798	31.0

average $k_B = 30.0\text{ N/m}$

d. The values for k_B are shown in the chart.

e. The average k values are shown below the previous two charts.

$$\begin{aligned}\text{percent difference} &= \frac{\left|k_{A_{ave}} - k_{B_{ave}}\right|}{k_{A_{ave}}} \times 100\% \\ &= \frac{|30.1 - 30.0|}{30.1} \times 100\% \\ &= 0.3\%\end{aligned}$$

You should have found that there is little difference between the values. Any difference is probably due to the displacement being measured with less accuracy than the period.

2. a. Regardless of the system chosen, both mass and amplitude of vibration will be controlled.

b. The following measurements would be made:

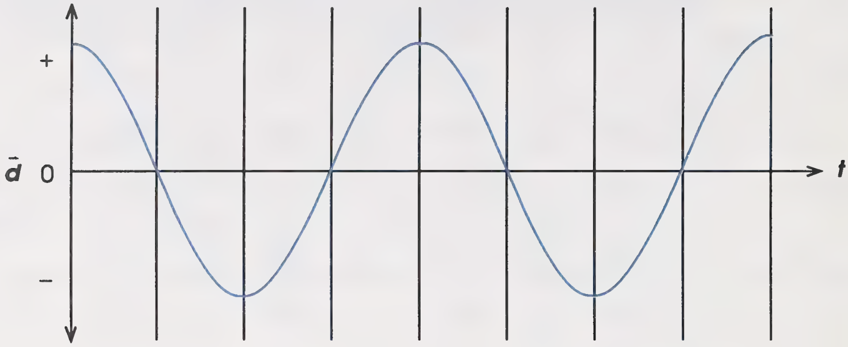
- Measure the mass using a balance.
- Measure the displacement of the oscillation or vibration.
- Use the mass to compute the restoring force.
- Compare the restoring force and displacement.

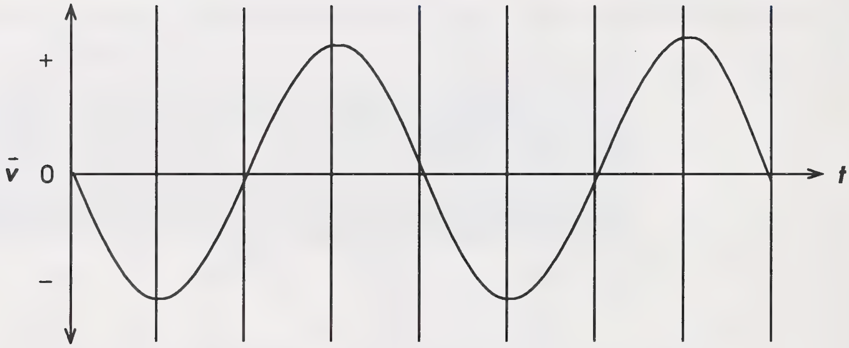
3. a. The pattern on the glass will represent a displacement versus time graph.

   b. The pattern on the graph shows two complete cycles or two complete oscillations.

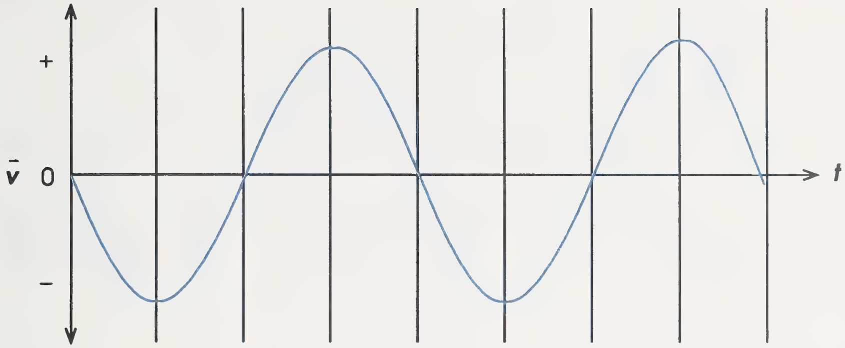
   c. The pattern on the glass represents simple harmonic motion.

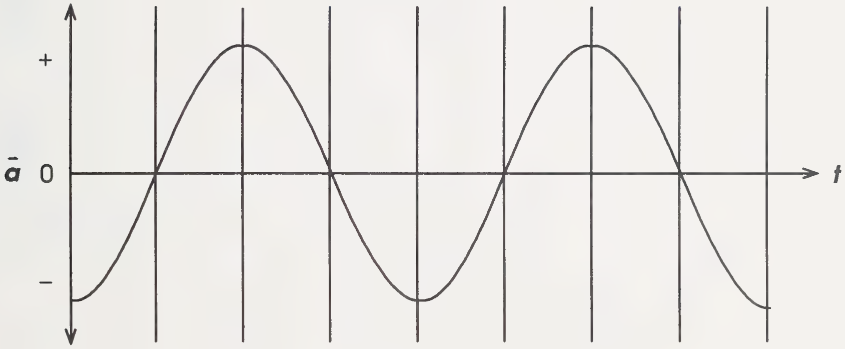
   d.





e.





Ticker Tapes for Section 1: Activity 4 Part B

Ticker tape pulled at
a constant speed
for 2.00 seconds
To find the time
interval between dots,
follow this equation.

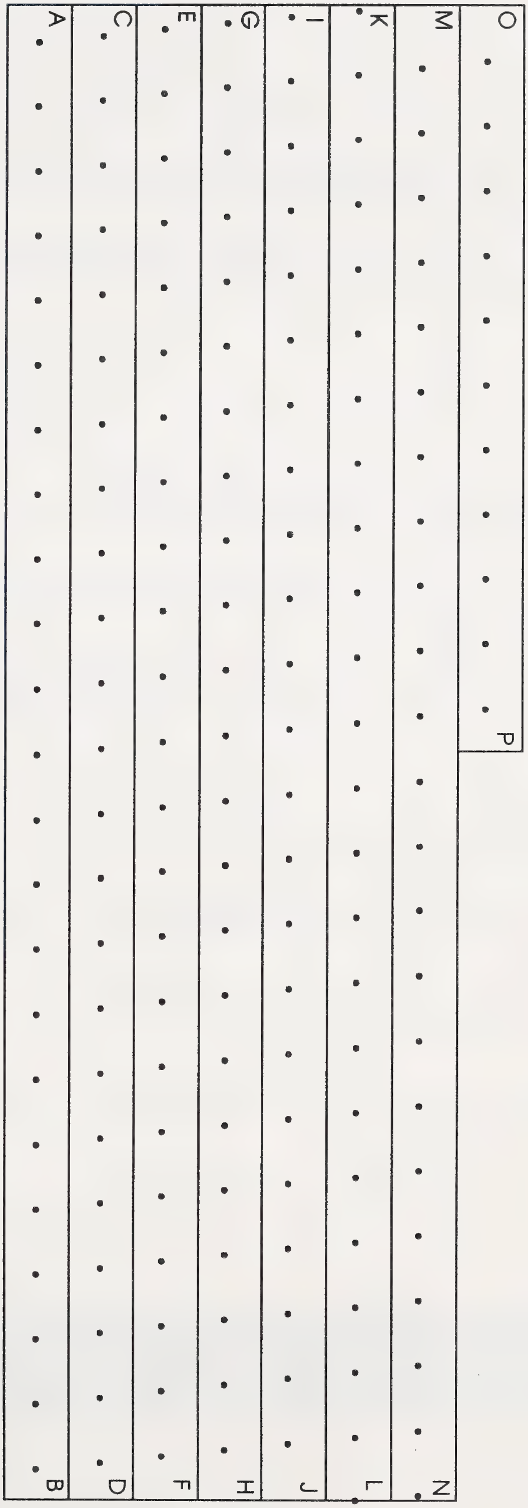
$$\frac{2.00\text{ s}}{\text{number of dots}}$$

↓

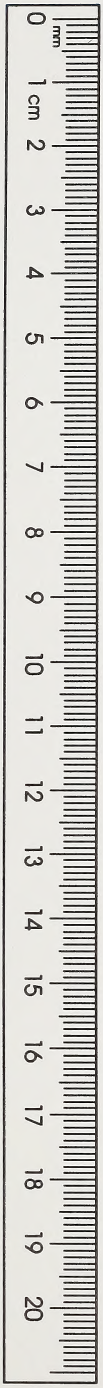
$$\frac{2.00\text{ s}}{\boxed{}}\text{ dots}$$

↓

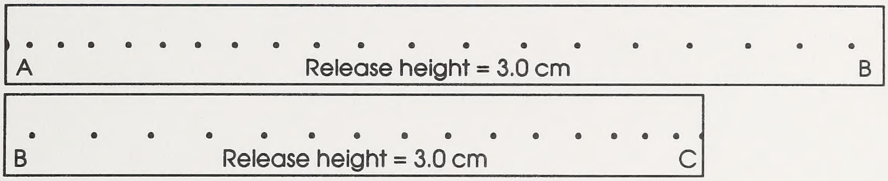
$\boxed{}$ s/dot



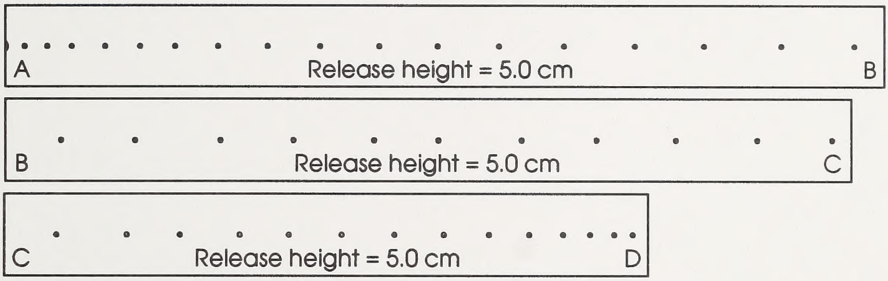
Ticker Tapes for Section 1: Activity 4 Part B



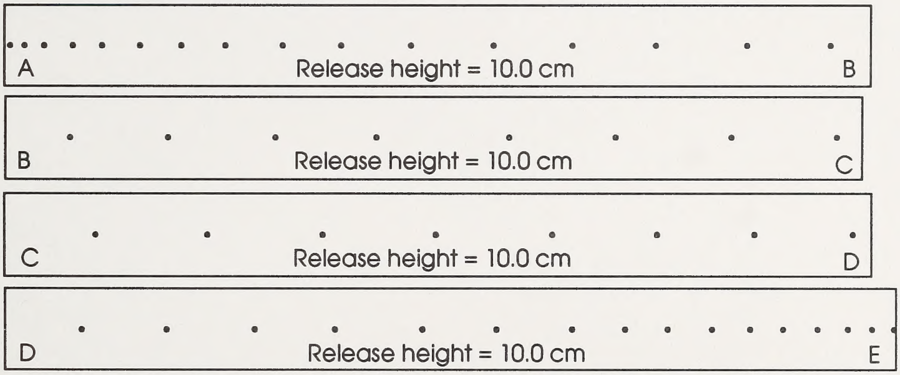
Trial 1



Trial 2



Trial 3



If you have any problems analysing these dots, check back with Module 2 where you followed a similar procedure.

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Physics 20

Student Module Booklet
Module 4

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